National Research Council Canada
Conseil national de recherches Canada

Canadian Electrical Association
Association Canadienne de l'Electricité

LIGHTING CONTROL

CONTRÔLE DE L'ÉCLAIRAGE

Proceedings of the CEA/DBR Symposium
Ottawa, June 28, 1984

Compte rendu du symposium de l'ACE/DRB
Ottawa, le 28 juin 1984

Proceedings No. 9
Division of Building Research
Price $8.00

NRCC 23989

Compte rendu N° 9
Division des recherches en bâtiment
Prix $8

Canada

5-3189/

NATIONAL RESEARCH COUNCIL CANADA
DIVISION OF BUILDING RESEARCH

CONSEIL NATIONAL DE RECHERCHES CANADA
DIVISION DES RECHERCHES EN BÂTIMENT

Lighting Control

Contrôle de l'éclairage

Proceedings of a symposium
sponsored by the Canadian
Electrical Association and the
Division of Building Research
June 28, 1984

Compte rendu du symposium parrainé
par l'Association canadienne de
l'électricité et la Division des
recherches en bâtiment
le 28 juin 1984

Proceedings No. 9
of the
Division of Building Research
Ottawa, August 1984

Compte rendu n° 9
de la
Division des recherches en bâtiment
Ottawa, août 1984

Price $8.00
NRCC 23589

Prix 8$
NRCC 23589

This symposium was sponsored by the Canadian Electrical Association and the Division of Building Research, National Research Council of Canada.

Ce symposium fut parrainé par l'Association canadienne de l'électricité et la Division des recherches en bâtiment, Conseil national de recherches du Canada.

© National Research Council of Canada 1984
Conseil national de recherches du Canada 1984

TABLE OF CONTENTS

TABLE DES MATIÈRES

	Page	
INTRODUCTION M.S. Rea, Symposium Chairman	1	**INTRODUCTION** M.S. Rea, Président du symposium
PAPERS **Lighting Control: Two Attitude Surveys** L.A. Carrière, R.R. Jaekel, M.S. Rea	3	**DOCUMENTS** **Contrôle de l'éclairage: Deux enquêtes d'opinion** L.A. Carrière, R.R. Jaekel M.S. Rea
Lighting Control: The Role of Advanced Technology - Past, Present, Future R.R. Verderber, F.M. Rubinstein	28	**Contrôle de l'éclairage: Le rôle de la technologie de pointe - le passé, le présent, le futur** R.R. Verderber, F.M. Rubinstein
Lighting Control: Impact on Energy V.H.C. Crisp	44	**Contrôle de l'éclairage: Impact sur l'énergie** V.H.C. Crisp
Lighting Control: The Client's Point of View A.W. Levy	61	**Contrôle de l'éclairage: Le point de vue du client** A.W. Levy
Lighting Control: The User's Point of view P.R. Boyce	69	**Contrôle de l'éclairage: Le point de vue de l'utilisateur** P.R. Boyce
Lighting Control: Application and Integration T.K. McGowan	86	**Contrôle de l'éclairage: Application et mise en oeuvre** T.K. McGowan
CLOSING REMARKS **Lighting Control: Some Conclusions** M.S. Rea	101	**CLÔTURE** **Contrôle de l'éclairage: conclusions** M.S. Rea
LIST OF ATTENDEES	111	**LISTE DES PARTICIPANTS**

INTRODUCTION TO THE LIGHTING CONTROL SYMPOSIUM

Part of the research programs at the National Research Council/Division of Building Research (NRC/DBR) and the Canadian Electrical Association (CEA) are devoted to the development of techniques for reducing energy consumption and operational costs in buildings. We have become increasingly interested in lighting control as a way of meeting these objectives.

Various new methods and techniques to control lighting, developed primarily to reduce lighting energy consumption in buildings, have stimulated the interest of many lighting researchers and professionals in this area. Because of this recent interest and the potential significance for reducing lighting energy consumption, we saw it as both timely and important to have a gathering of individuals interested in lighting control. To our knowledge this is the first symposium devoted entirely to this topic in North America.

From the papers and discussions at this symposium we expect to develop our research and communication programs at NRC/DBR and at CEA. Hopefully, this symposium will also influence other researchers and their programs as well as educators, engineers, consultants, designers, and manufacturers in the lighting field.

Mark S. Rea, Ph.D.
Symposium Chairman
Ottawa, June 28, 1984

Introduction au symposium sur le contrôle de l'éclairage

Une partie de la recherche effectuée par le Conseil national de recherches du Canada (CNRC), la Division des recherches en bâtiment (DRB) et l'Association canadienne de l'électricité (ACE) est consacrée à la mise au point de techniques destinées à réduire la consommation d'énergie et les coûts opérationnels des bâtiments. De plus en plus, on se tourne vers le contrôle de l'éclairage pour atteindre ces objectifs.

Une variété de nouvelles méthodes de contrôle de l'éclairage, mises au point principalement dans le but de réduire la consommation d'énergie requise pour l'éclairage des bâtiments, ont stimulé l'intérêt d'un grand nombre de chercheurs et de spécialistes dans ce domaine. En raison de ce récent intérêt et des retombées probables d'un tel évenement sur les économies d'énergie pour l'éclairage, nous avons cru important de rassembler tous ceux intéressés au contrôle de l'éclairage. Il s'agit à notre connaissance, du premier symposium entièrement consacré à ce sujet en Amérique du Nord.

Nous croyons que les communications présentées lors de ce symposium et les discussions qui suivront, contribueront au développement des programmes de recherche et de communication du CNRC, de la DRB et de l'ACE. Il est à espérer que ce symposium profitera également à d'autres chercheurs de même qu'aux enseignants, ingénieurs, experts-conseils, concepteurs et fabricants qui travaillent dans le domaine de l'éclairage.

Mark S. Rea, Ph.D.
Président du symposium
Ottawa, le 28 juin 1984

LIGHTING CONTROL:
Two Attitude Surveys

L.A. Carrière, R.R. Jaekel, M.S. Rea

ABSTRACT

Two surveys to probe the attitudes of lighting professionals on lighting control indicate that respondents, in general, prefer a mixed approach combining local, manual switching designed to meet the needs of the user and central, automatic 'fail safe' features (e.g. scheduled switching) designed to reduce wasted lighting energy.

CONTRÔLE DE L'ÉCLAIRAGE:
Deux enquêtes d'opinion

L.A. Carrière, R.R. Jaekel, M.S. Rea

RÉSUMÉ

Deux sondages pour recueillir l'opinion des professionnels de l'éclairage concernant le contrôle de l'éclairage révèlent qu'en général, les répondants sont en faveur d'une approche mixte, combinant des interrupteurs manuels locaux conçus pour répondre aux besoins des utilisateurs et des dispositifs automatiques centraux à sûreté intégrée (par exemple les interrupteurs à minuterie), conçus pour réduire le gaspillage de l'énergie pour l'éclairage.

Louis A. Carrière
CEA/NRCC Industrial Fellow, Lighting Research
Energy and Services Section
Division of Building Research
National Research Council Canada
Ottawa, Ontario
K1A 0R6

ABOUT THE AUTHOR

Louis Carrière graduated with a Bachelor of Science, Honours in Physics from Carleton University (Ottawa) in 1982. Since March 1983 he has been working on a Lighting Fellowship Program sponsored by the Canadian Electrical Association (CEA) at the National Research Council Canada (NRCC). The lighting research carried out under the Fellowship is conducted in conjunction with and guided by, a team of lighting researchers in the Division of Building Research at NRCC.

Louis A. Carrière
Boursier de recherche de l'ACE et du CNRC
Section énergie et équipements
Division des recherches en bâtiment
Conseil national de recherches du Canada
Ottawa, Ontario
K1A 0R6

L'AUTEUR

Louis Carrière a obtenu en 1982 un baccalauréat en science, avec spécialisation en physique de l'Université Carleton à Ottawa. Depuis mars 1983, il travaille au Conseil national de recherches du Canada (CNRC) dans le cadre d'un programme de bourses parrainé par l'Association canadienne de l'électricité (ACE). Les études sur l'éclairage entreprises dans le cadre de ce programme sont effectuées avec la collaboration et sous la direction d'une équipe de chercheurs de la Division des recherches en bâtiment du CNRC.

R.R. Jaekel
Technical Officer
Energy & Services Section
Division of Building Research
National Research Council of Canada
Ottawa, Ontario
K1A 0R6

ABOUT THE AUTHOR

Ralston Jaekel joined the National Research Council, Division of Building Research, after graduating from Algonquin College (Ottawa) in 1964. He was involved with several projects associated with the calculation and measurement of transient cooling loads until 1977. He then joined the newly formed lighting research group of the Energy & Services Section, being actively engaged in the light use and energy conservation program.

R.R. Jaekel
Agent technique
Section énergie et équipements
Division des recherches en bâtiment
Conseil national de recherches du Canada
Ottawa, Ontario
K1A 0R6

L'AUTEUR

Ralston Jaekel est entré au service de la Division des recherches en bâtiment du Conseil national de recherches en 1964 après avoir complété ses études au Collège Algonquin d'Ottawa. Jusqu'en 1977, il a participé à plusieurs projets de recherche sur le calcul et la mesure des charges calorifiques transitoires. Il s'est alors joint au nouveau groupe de recherche sur l'éclairage de la Section énergie et équipements, se consacrant activement au programme sur l'éclairage et les économies d'énergie.

Dr. M.S. Rea
Research Officer
Energy & Services Section
Division of Building Research
National Research Council of Canada
Ottawa, Ontario
K1A 0R6

ABOUT THE AUTHOR

Dr. Rea did his post-graduate work at the Institute for Research in Vision at Ohio State University, and received his Ph.D. in sensory biophysics in August 1978. Since that time he has been employed at the National Research Council of Canada. He is an official Canadian delegate to the Commission Internationale de l'Éclairage, the chairman of the Illuminating Engineering Society, Committee for the Recommendation on the Quality and Quantity of Illumination (RQQ), and executive secretary to the National Research Council Office of Lighting Research.

M.S. Rea
Agent de recherche
Section énergie et équipements
Division des recherches en bâtiment
Conseil national de recherches du Canada
Ottawa, Ontario
K1A 0R6

L'AUTEUR

M.S. Rea a fait des études supérieures à l'Institute for Research in Vision de la Ohio State University où il a obtenu son doctorat en biophysique sensorielle en août 1978. Depuis, il est à l'emploi du Conseil national de recherches du Canada. M. Rea est délégué officiel canadien auprès de la Commission internationale de l'éclairage, et président du Committee for the Recommendation of the Quality and Quantity of Illumination (RQQ) de la Illuminating Engineering Society. Il est de plus secrétaire de direction du Bureau de la recherche sur l'éclairage du Conseil national de recherches.

1. INTRODUCTION

1.1 Background

Since the mid-1970s many techniques have been implemented to reduce lighting energy consumption in buildings. These include more efficient lamps and hardware, delamping, daylighting, implementation of electronic control equipment, introduction of more manual wall switches, and even closing sections of buildings. In recent years the emphasis on saving energy has partially eclipsed the very reasons why lighting is installed, namely to permit people to perform tasks. It is difficult to obtain accurate or complete assessments of the effects that lighting has on worker productivity and satisfaction; however, there may be severe financial penalties, caused by reduced worker efficiency, associated with some of these approaches to saving lighting energy.

Lighting controls that enable one to modulate the lighting, through switching and dimming, are attractive ways to save energy. Substantial energy savings can be made with less chance of compromising the 'quality or quantity' of illumination and, thus, the productivity or satisfaction of workers. Rather than delamp, for example, energy could be saved by simply turning the lights 'off' when no one occupies a space.

1.2 Purpose

There has been a growing interest in lighting control among lighting professionals, and it was important to document their attitudes on the subject for this symposium. In this way the views of the speakers at the symposium can be compared to the collective opinions of working lighting professionals. What is more, these views and opinions about lighting control can be used to develop more effective programs of research and communication. Ultimately these activities should translate into more efficient building operations.

1.3 The Surveys

In this paper the results of two surveys, conducted between September 1983 and May 1984, on the modulation of light through controls, are presented. Both questionnaires focussed on the objectives, factors and methods of controlling lighting. An understanding of these three aspects seemed essential to the evaluation of alternative lighting control strategies. The first survey consisted of open-ended questions designed to encourage respondents to provide unfettered answers. The responses to this questionnaire provided us with feedback for a subsequent, objectively scored questionnaire. For this second survey, respondents were asked to complete multiple choice and rank-order questions pertaining to three examples of building spaces, (A) an open-plan office, (B) a retail store, and (C) an elementary school classroom. To a large extent, the answers to the second questionnaire confirmed our inferences about the respondents' attitudes toward lighting control gleaned from the first questionnaire.

Over 350 individuals from various disciplines and associated with various aspects of lighting responded to one or both of our mailed surveys. This number represented more than half of the people who were contacted. This fraction was encouraging, as a much smaller proportion of those receiving questionnaires through the mail usually respond.

Surveys provide a wealth of data, and these were no exception. Only the highlights are given in this paper. For those interested in more details (e.g. manufacturers), a complete listing of the data is available upon request from the authors.

1.4 Outline

The body of this paper consists of four sections dealing with:

BACKGROUND INFORMATION: Information about the respondents;
OBJECTIVES: The respondents' perceived reasons for lighting control;
FACTORS: Those aspects of the lighting system, the building, and the user seen by the respondents as important in the selection of a way to control lighting;
METHODS: Those techniques preferred by respondents to control the lighting.

2. BACKGROUND INFORMATION

2.1 Survey 1

Originally we supposed that different categories of lighting professionals might view lighting control differently. In the first questionnaire we followed a traditional method of categorizing respondents. We listed many descriptors to which the respondents could classify themselves. Table 1 shows the number of responses in each of the categories used in the first questionnaire; 224 of 489 mailed surveys were returned. Some respondents checked more than one category to describe themselves.

TABLE 1 (Survey 1) NUMBER OF RESPONDENTS IN EACH CATEGORY

"What best describes your title or position?"

Categories and number of responses

Engineer	94	Utility rep	13
Consultant	62	Architect	11
Other	36	Manufacturer rep	9
Designer	31	Building manager	5
Researcher	26	Building owner	2
Educator	20	General user	1

These descriptive data are useful in determining what kind of lighting professionals responded, or at least how the respondents viewed themselves. The respondents primarily considered themselves to be engineers. Architects and building managers, for example, were not well represented in this first survey. Although the individual responses to the open-ended questions were varied, there did not seem to be any clear-cut differences in responses between the various categories of respondents. Categorization of this type was not particularly useful for this kind of analysis because there were too many categories and too few respondents in most categories.

2.2 Survey 2

In the second questionnaire we concentrated on a few comparisons that appeared promising from the first questionnaire or ones that we had not previously considered. For example, we were interested in any differences between respondents who were and who were not directly involved with the lighting designs. Perhaps the latter group would have been less 'practical' and would opt for more complex lighting control systems. We were also interested in any differences between respondents in various countries, particularly Canada and the United States. Perhaps different climatic conditions, available daylight, or typical utility rates would be reflected in their respective opinions about methods of lighting control. Table 2 lists the percentages of respondents in each of the classification categories employed in the second survey, as well as the frequency of Canadian and American respondents. Of 678 questionnaires, 300 were completed and returned in this second survey.

Answers to the questions in the second survey varied greatly among respondents, as in the first one, but there were no large differences between respondents in the different categories. In other words, the variation among categories of respondents was small relative to the variation among respondents within a given category. Even the differences between respondents in Canada and in the United States were very small, despite typically different utility rates, for example. The largest differences between categories were in the neighbourhood of 30%, and these 'large' differences were almost always associated with the open-plan office. Except for a few cases, there was general unanimity between categories of respondents for the retail store and the classroom. When there were differences between categories of respondents, the largest differences were usually between those more aligned with engineering and those more aligned with architecture. For example, about 25% more architects than engineers preferred to incorporate manual dimming in the lighting control scheme for the open-plan office. More will be said about the larger differences between categories of respondents in later sections.

TABLE 2 (Survey 2) PERCENTAGES OF RESPONDENTS IN EACH CATEGORY

Category questions and percentages of responses

1. "Are you employed in the private sector?"

   69.8% yes

   28.5% no

   (1.7% said they were employed in both the private and public sectors.)

2. "Do you consider your activities more closely aligned with engineering or architecture? (Check only one)

   70.9% engineering

   21.4% architecture

   5.7% neither

   (2.0% said they were associated with both engineering and architecture.)

3. "Are you directly involved with the management or operation of buildings?"

   20.8% yes

   79.2% no

4. "Are you directly involved with the layout and design of buildings or their components?"

   69.2% yes

   30.1% no

   (0.7% checked both answers)

National Origin:

Canadian respondents	56.2%
American respondents	38.8%
Other	5.0%

3. OBJECTIVES

3.1 Survey 1

It is important to determine what reasons lighting professionals have for using lighting controls and for choosing one control technique over another. In the first questionnaire we asked: 'What are the main objectives for controlling lighting?' We believed that most respondents would write 'to save energy' or 'to reduce costs'. These were, in fact, common answers, but responses concerning 'the needs of the user' were also prevelant. A less frequent, but distinct objective was related to the 'visual impact or impression' provided by lighting controls as, for example, with signal lights or aesthetics. Some of the responses are listed in Table 3. This table illustrate both the diversity and the common, but implicit, themes in the responses.

TABLE 3 (Survey 1) SOME PARAPHRASED RESPONSES TO THE QUESTION:

"What do you consider should be the main objectives for controlling lighting?"

Responses

Cost objectives	User objectives	Other objectives
cost of operation	meet users needs	creation of visual effects
energy conservation	quality of light	visual night effect
minimum maintenance	flexibility	
interaction with daylight	variable intensity	
provide light in small areas		
peak load reduction		
convenience		
effective control location		

Note: These categories are not mutually exclusive. Some respondents may have given answers in more than one category.

3.2 Survey 2

From the answers to the first questionnaire we formulated four broad objectives for use in the second questionnaire that seemed to capture the essence of all the responses. Respondents to the second questionnaire were asked to rank-order the four objectives related to 'why lighting controls would be installed in a building' for three

different spaces, (A) an open-plan office, (B) a retail store, and (C) an elementary school classroom. From the rank-orderings of these four objectives we could provide a statisitcal representation of the respondents' attitudes toward the objectives for light control. The four objectives and the average rank-orders for the three different spaces are presented in Table 4.

Not only was it important to determine why respondents wanted to have lighting controls, but it was also important to determine why respondents would choose one particular lighting control over another. For example, do professionals base their decisions only on first costs, or do they prefer to employ methods with the best payback? We felt that we could focus on the important reasons for selecting a ligthing control asking the respondents to rank-order the four objectives presented in Table 5. As in Table 4, the average rank-orders for the three different spaces are also presented.

From the responses in Tables 4 and 5, respondents felt it was most important for the lighting control to meet the users' needs, both terms of acceptance and flexibility. Closely followed in preference was the reduction in net operating costs with the best payback period. Conserving natural resources and low initial costs were the objective usually rated the lowest by the respondents. This general picture was true for the three classes of building space, implying that, despite the different functions of these buildings, the objectives for installing lighting controls (Table 4) and the objectives for choosing a particular lighting control (Table 5) are more or less the same. The respondents to both questionnaires gave us the same general impression as to their objectives for lighting control, as evidenced by comparing Table 3 with Table 4 and 5.

It is curious to note that initail costs were rated as the lowest objective for selecting a lighting control; this is in contrast to the recent paper by Verderber and Rubinstein (1983), where they report that initial cost is a dominating factor in selecting a lighting control. Perhaps the responses to this question represent more what professionals <u>want</u> rather than what is actually done in selecting a method of lighting control

4. FACTORS

4.1 Survey 1

Obviously, many factors can be considered in the design and operation of lighting control. These factors may be related not only to the lighting system (e.g. initial costs of the equipment), but also to other aspects of a building (e.g. the HVAC system). Respondents were asked to answer two open-ended questions related to the factors important to lighting control in the first questionnaire. These questions, with some actual responses, are presented in Tables 6 and 7.

TABLE 4 (Survey 2) AVERAGE RANK-ORDERS TO THE QUESTION:

"Rank order from 1 (highest) to 4 (lowest).
Why would the lights be controlled in the _____?"

	Open-Plan Office	Retail Store	Elementary School
A. Conserve our natural resources	3.1	3.6	3.3
B. Visual impact or impression	3.3	2.0	3.1
C. Meet the user's needs	1.6	2.0	1.4
D. Reduce the net operation costs	1.9	2.3	2.1

For each objective, the average rank-order = $\frac{\Sigma \text{ (rank-orders)}}{\text{number of responses}}$.

TABLE 5 (Survey 2) AVERAGE RANK-ORDERS TO THE QUESTION:

"Rank order from 1 (highest) to 4 (lowest).
Why would you choose a particular way to control lighting in the _____?"

	Open-Plan Office	Retail Store	Elementary School
A. Best payback	2.4	2.4	2.6
B. Low initial cost	3.5	3.1	3.3
C. User acceptance	2.1	2.0	1.9
D. Flexibility for different uses	2.0	2.4	2.2

For each objective, the average rank-order = $\frac{\Sigma \text{ (rank-orders)}}{\text{number of responses}}$.

TABLE 6 (Survey 1) SOME PARAPHRASED RESPONSES TO THE QUESTION:

"What information do you think is needed before choosing a method of controlling the lighting?"

Responses

Cost factors	User factors	Other factors
budget considerations	user needs	type of lighting
cost of energy	tasks	design of space
reliability	occupancy patterns	previous success
daylight available	motivation of users	architectural use
economics	who uses the controls	bldg. management system
	flexibility	safety
		lighting standards
		laws

Note: These categories are not mutually exclusive. Some respondents may have given answers in more than one category.

TABLE 7 (Survey 1) SOME PARAPHRASED RESPONSES TO THE QUESTION:

"What impact do lighting controls have on things other than the lighting system?"

Responses

Cost factors	User factors	Other factors
HVAC	productivity	security and fire safety
capital and operating costs	mood and morale	indoor plants
energy costs	flexibility	develop energy consciousness
rent	visibility	marketability of building space
lamp replacement	aesthetics	pollution of environment
electrical demand charges	use of controls	building effectiveness
energy waste	time spent reaching controls	electrical line effects
maintenance costs	video terminals	electrical distribution system
power consumption	convenience	image
boiler and chiller size		

Note: These categories are not mutually exclusive. Some respondents may have given answers in more than one category.

Two aspects of the answers are worth noting. First, many different factors were cited by the respondents to both questions. Still, as in Table 3, there seem to be two common, but implicit, themes in most of these answers related to the user and to the operational or installation costs. Second, respondents had a good working knowlege of these many factors. This should not be surprising as most of the respondents were engineers, most were in the private sector, and most were actually doing lighting designs.

4.2 Survey 2

Given this wide variety of detailed factors associated with lighting control, one could not expect to obtain valid information about the preferred methods for lighting control without specifying some of the more important factors. For example, one could not expect respondents to give information about photoelectric dimming without having some relevant information about windows or skylights. In the second questionnaire we simply listed some important factors, gleaned from the first questionnaire, that should be considered in three kinds of building space: (A) an open-plan office, (B) a retail store and (C) an elementary school classroom. The factors common to these three kinds of building space are listed in Table 8. These factors were defined on a cover sheet preceeding the questions related to the three kinds of building space. Presumably this information was retained by respondents while answering the questions. Those factors specific to the three kinds of building space are listed in Table 9. These factors were listed at the top of each response sheet; one response sheet was used for each of the examples of building space.

In the second questionnaire, there was one specific question regarding the factor of daylight for each of the three building spaces. Figure 1 shows the percentages of respondents who said 'yes' to the question, "Would daylighting be a factor in arranging the control circuits?" Answers to these questions clearly show that there is an overwhelming desire to incorporate daylighting into the lighting control scheme in the office and the classroom.

TABLE 8 (Survey 2) LIST OF COMMON FACTORS PRESENTED IN THE SECOND QUESTIONNAIRE

FACTORS TO CONSIDER IN THE THREE EXAMPLES

The three examples of spaces (A, B and C) have several factors in common. These factors should be considered when answering the questionnaire. You should assume that:

1) This is a building planned for construction.

2) The building will be in the northern USA or southern Canada.

3) The budget allotted for the lighting system is average; it is neither excessive nor austere.

4) The electrical operating costs would be average for a North American city.

5) The building's mechanical system provides heating and cooling throughout the year.

6) Large windows would be on the north side of the space.

7) Fluorescent ceiling lighting is to be used throughout the space.

8) In each case the building will be owned by the employer of the individuals working in the space.

TABLE 9 (Survey 2) LIST OF SPECIFIC FACTORS FOR EACH BUILDING SPACE PRESENTED IN THE SECOND QUESTIONNAIRE

SITUATION A

OPEN-PLAN OFFICE

- Administration section for an insurance company
- Staff of 30 people
- Work areas separated by six-foot partitions
- Occupies one fourth of one floor in a 20-storey building
- 09:00 to 18:00 occupancy with occasional overtime.

SITUATION B

RETAIL STORE

- Large, one-storey discount store selling general merchandise with five-foot high display shelves organized by departments throughout the store
- Consider only the sales area
- Isolated building
- 08:00 to 22:00 six days a week.

SITUATION C

ELEMENTARY SCHOOL

- 25 student classroom
- One-student desks aligned in rows
- Activites include lectures, reading groups, and movies
- One-storey, 30-classroom school with gymnasium and cafeteria
- Periodic full occupancy during the school day. A class session lasts approximately 45 minutes
- Rarely used outside school hours.

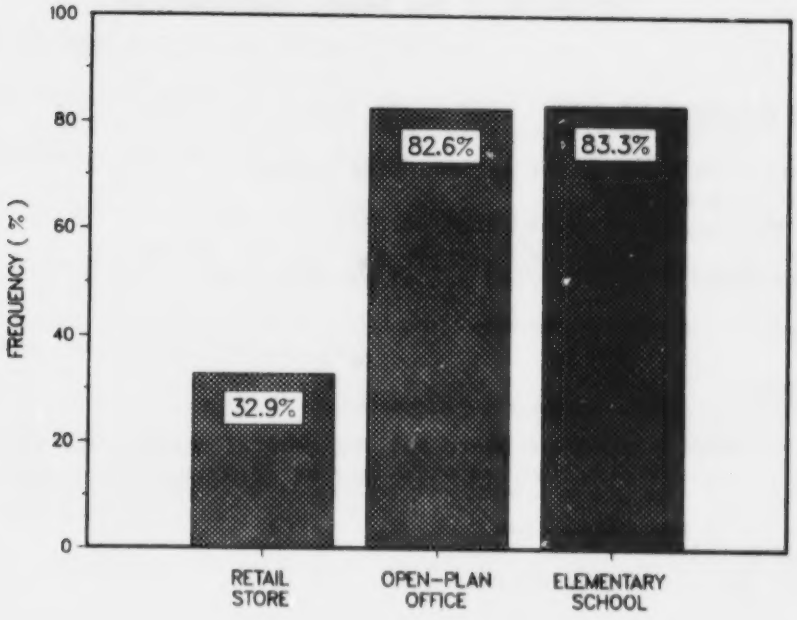


Figure 1. (Survey 2) Percentages of respondents who considered daylighting an important factor in arranging control circuits for these three types of building spaces.

5. METHODS

5.1 Survey 1

In the first questionnaire respondents were asked: "What would be your preferred method for controlling lighting?" We wanted respondents, when answering this question, to provide us with a general picture of how they preferred to control lighting. As noted in section 4.2, respondents could not be expected to give specific answers to this question without knowing something about the important factors. In fact, it may have been too optimistic to expect them to give even general answers to this question. Nevertheless, to obtain a clear indication of the general approach preferred by respondents, it was necessary to receive information in the following three categories (Lowry and Rea, 1981):

1) switching - dimming
2) manual - automatic
3) local - central.

The elements of these categories are not binary. A manual dimmer in a dining room, for example, usually has on-off switching as well. Further, these categories are not completely independent. For

example, local and manual (e.g. a wall switch) are usually closely associated, as are central and automatic (e.g. a computerized system), even though one can find examples of local-automatic hardware (e.g. a wall timer switch) or central-manual hardware (e.g. a circuit breaker panel). These assumed asssociations were not sufficient, however, for us to confidently draw inferences about most respondents' preferred methods of lighting control. Only about one quarter of the respondents provided information from all three categories above.

Those methods provided by the respondents to this question were quite diversified. Table 10 presents some of these answers, but because of our uncertainty about most of the respondents' preferred methods for controlling the lighting, no attempt was made to categorize these responses. About 15% of the respondents took exception to this question because they believed more information about the situation (i.e. the important factors) was necessary before a 'preferred method' could be described. Some of these comments are also given in Table 10.

5.2 Survey 2

The second questionnaire included questions directly related to the three categories presented in Section 5.1 for describing the method for controlling the lighting. From these questions it was possible to obtain a less ambiguous picture of the respondent's preferred methods for lighting control.

Table 11 shows the matrix format chosen for determining respondents' attitudes toward the switching-dimming category, the manual-automatic category, and their combination. Respondents had to mark those boxes representing their preferred methods for controlling lighting in (A) an open-plan office, (B) a retail store and (C) an elementary school classroom. The frequencies of responses in each box are also shown in Table 11. Figure 2 shows the combined frequency of responses for switching, dimming or both in the three building spaces. Figure 3 shows the combined frequency of responses for manual, automatic or both. Table 11 and Figures 2 and 3 can be summarized as follows:

1) Every box received some check marks. Manual switching was almost always selected by the respondents. Scheduled switching (timing) was the most popular automatic option but was closely followed in popularity by photoelectric dimming and switching. Manual dimming was also popular in some cases. Power demand sensing, using switching or dimming, was the least popular option (Table 11).
2) Although the differences are small, there was some discrimination by respondents between the 'on' and 'off' functions of switching (Table 11). Manual switching was preferred for the 'on' function while automatic switching was preferred for the 'off' function.
3) About half the respondents preferred to use just switching; the other half wanted to use both switching and dimming (Figure 2).

TABLE 10 (Survey 1) SOME PARAPHRASED RESPONSES TO THE QUESTION:

What would be your preferred method for controlling lighting?

Responses

Methods

- 2-level switching
- overriding switching by work area
- remote switching capabilities
- local switching and training occupants to use them sensibly
- dimming
- manual control
- manual on with automatic off
- automatic but not economical at present
- automatic with manual over-rides
- automatic off and demand on
- motion detectors, occupancy detectors
- perimeter lighting by a mix of P.E. cell and computer/timer
- photocell over-rides
- photocell on and time clock off
- micro-processor with low voltage relay control
- micro-processor-based controls with power line communications
- automatic to serve as a "reminder" or "sweeping up" operation
- integrated system which periodically scans the lighting circuits to keep lighting to predetermined schedule
- individual controls
- area type controls designed for a specific area
- central control
- task-oriented lighting versus a general uniform lighting
- energy efficient system
- hardware control interface with energy management system
- educate the user
- phantom tubes

Exceptions

- anyone who prefers a single method is too closed-minded
- this is a loaded question. One must look into the system as a total
- depends on task
- different situations call for different solutions
- depends on application and on budget restraints
- depends on the cost-benefit analysis
- since we are a manufacturer of this product, we naturally feel in most instances this is the best way.

4) Generally respondents prefered to use a combination of manual and automatic features to control the lights (Figure 3).
5) Preferences were more or less the same for the three building spaces (Table 11). Two minor exceptions might be noted: Automatic occupancy sensing and automatic light sensing were not popular in the retail store.

Although not shown in this table and these figures, one of the few 'large' differences between Canadian and American respondents was with regard to the occupancy sensing options. About 33% of the American respondents wanted to have occupancy sensing switching in the office and in the school, but only about 17% of the Canadian respondents marked this option. Although a minority of respondents in both countries saw this approach as desirable, apparently it is of more interest in the United States than in Canada.

The only other 'large' difference between Canadian and American respondents was with regard to light sensing dimming. About 66% of the American respondents saw this as an important option in the open-plan office, whereas about 38% of the Canadian respondents thought so. Similarly, 54% of the American respondents saw this as desirable in the classroom compared with 30% of the Canadian respondents. One might infer from these responses that Canadian respondents are less enthusiastic about daylighting except that responses to light sensing switching were nearly identical for respondents from the two countries (both groups were about 24% in favor of light sensing switching) as were their responses to the question in section 4.2: "Would daylighting be a factor in arranging the control circuits?" (both groups were about 82% in favor of daylighting being considered in arranging the lighting control). Apparently the differences of opinion are related to photoelectric dimming in particular and not to daylighting in general.

As noted earlier in section 2.2, more architects than engineers perferred manual dimming in the open-plan office. This was also true in the retail store and the classroom, although to a lesser extent. In fact, differences in opinion between engineers and architects were the largest on this issue. Of course as noted earlier, these differences were not really very large, and even among architects, manual dimming was <u>not</u> perferred by the majority of the respondents. The only other 'large' difference between engineers and architects was with regard to automatic timing. Engineers were more likely to select automatic timed switching than architects in the open-plan office and the elementary school (there were a few respondents in both groups who were in favor of automatic timing in the retail store). Both groups favored automatic timed switching 'off' more than automatic timed switching 'on'. In total, however, the differences between these two groups, as well as between the other categories of respondents, were surprisingly small on most of these aspects of controlling the lighting.

TABLE 11 (Survey 2) PERCENTAGES OF RESPONSES TO THE QUESTIONS USED TO EXPLORE THE RESPONDENTS' ATTITUDES TOWARD SWITCHING, DIMMING, MANUAL AND AUTOMATIC LIGHTING CONTROL

"Describe the control system by checking as many boxes as required."

	OPEN-PLAN OFFICE			RETAIL STORE			ELEMENTARY SCHOOL		
	Switching On	Switching Off	Dimming	Switching On	Switching Off	Dimming	Switching On	Switching Off	Dimming
manual	80.7	70.2	18.3	77.8	74.4	21.8	87.3	81.2	30.5
automatic timing	37.6	61.4	8.1	53.9	62.1	9.9	37.3	56.2	7.5
automatic light sensing	21.0	25.8	47.5	13.7	13.7	18.4	20.5	25.0	38.0
automatic occupancy sensing	20.0	25.4	5.1	8.9	8.5	3.8	20.2	28.1	6.5
automatic power demand sensing	7.1	9.8	14.6	5.8	7.5	9.6	4.8	6.8	9.6

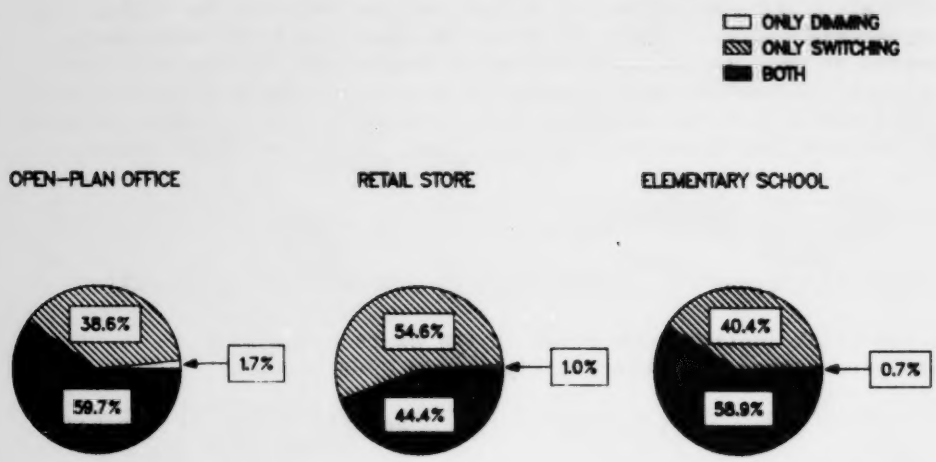


Figure 2. (Survey 2) Percentages of respondents wanting switching, dimming or both types of lighting control.

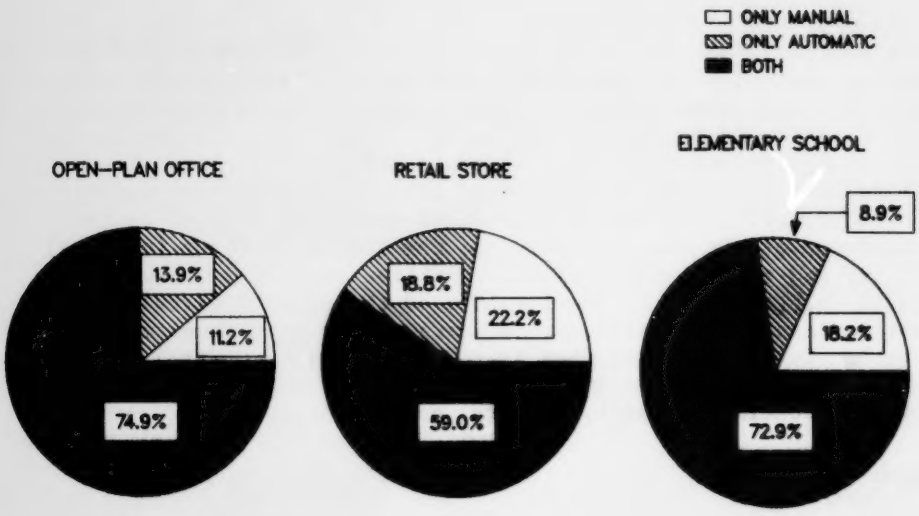


Figure 3. (Survey 2) Percentages of respondents wanting manual, automatic or both types of lighting control.

We were also interested in determining whether respondents believed that instructions to people about the use of lighting controls could be an effective method for controlling the lights and, thus, saving energy. Table 12 gives the question that respondents answered as well as the frequencies of responses. Respondents who considered themselves more closely aligned with engineering were more equally divided on the question than architects, 2/3 of whom believed that instructions would have a significant impact on light usage.

TABLE 12 (Survey 2) PERCENTAGES OF RESPONSES TO THE QUESTION:

"Do you think instructions given to the users would have a significant impact on the way lights are used in this _____?"

	Open-Plan Office	Retail Store	Elementary School
yes	58.7%	47.2%	64.8%
no	41.3%	52.8%	35.2%

It was more difficult to formulate questions related to the location of the lighting control devices (i.e. the category local-central), because it is difficult to clearly categorize certain lighting control situations. For example, is a wall switch on one floor of a high-rise office building a local or a central control device? It could be considered 'local' with respect to the control panel on the ground floor, but it could also be considered 'central' with respect to a work station in an office. Rather than quibble with pedantic definitions, we asked a set of questions related to the arrangement of the control circuits, the number of input (control) devices, and the existance of a centralized control device. Figures 4a,b,c relate to the location of the control circuits and input devices. In general, respondents wanted both local and central control. In other words, they seemed to prefer to control the lights locally, usually defined in terms of a logical work area, with one device in combination with a central control device.

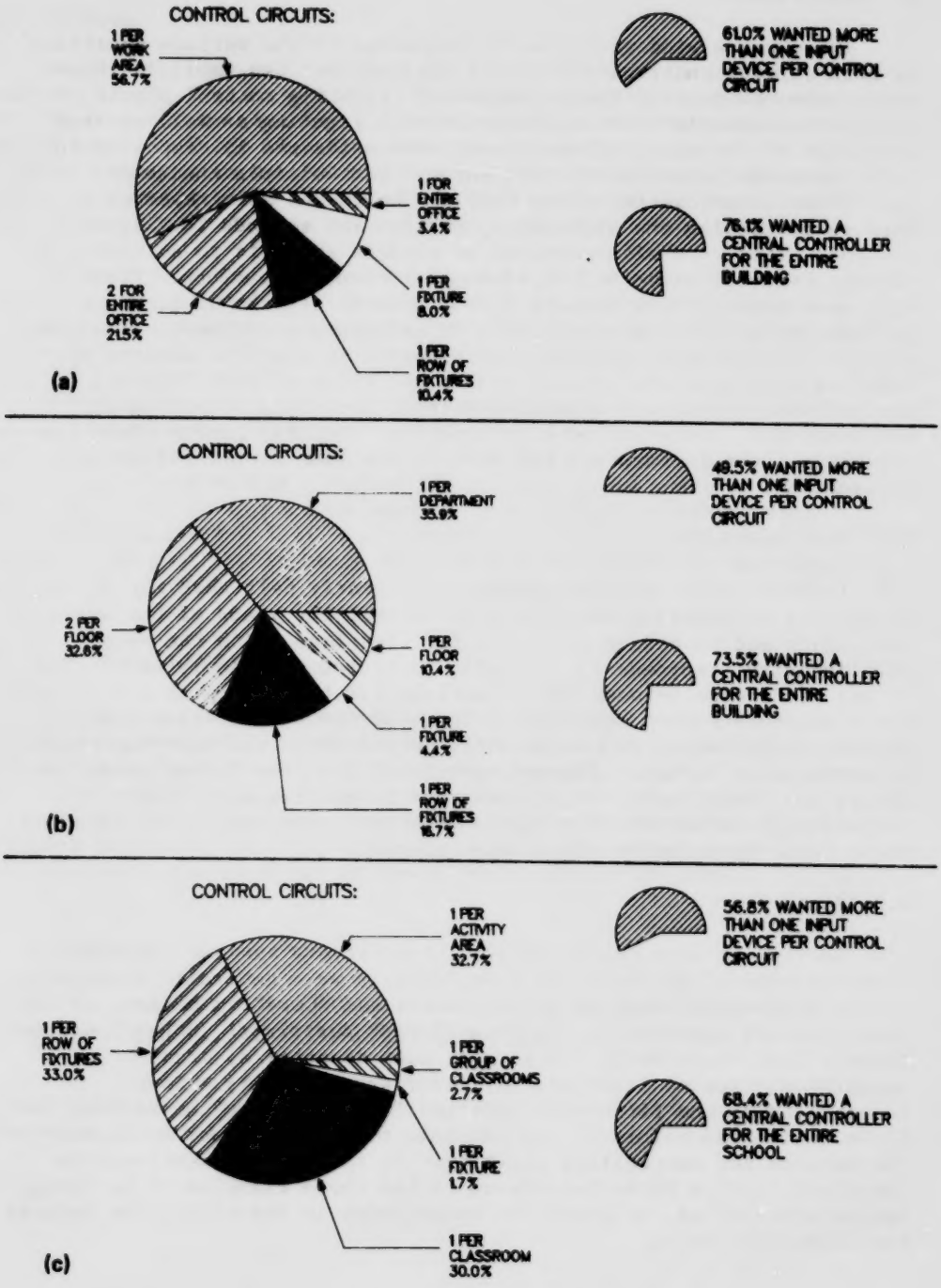


Figure 4. (Survey 2) Arrangement of control circuits and input devices for (a) open-plan office, (b) retail store, (c) elementary school.

6. CONCLUSIONS

There was a wide variation in responses to the various questions in both surveys concerning lighting control, but two implicit themes were common to most of these responses: lighting control should reduce the operation costs associated with lighting as well as meet the needs of the user. These themes were evidenced in responses to both open-ended questions (first survey) and multiple choice and rank-order questions (second survey). The themes were repeated in answers concerning the objectives, factors and methods for lighting control. They were also repeated in answers specific to an open-plan office, a retail store and an elementary school classroom. Finally, they were evidenced in answers from different classes of lighting professionals and from respondents in different countries. In short, despite idiosyncratic responses with regard to specific aspects of lighting controls, the typical respondent believed that lighting controls should be cost effective without adversely affecting the performance or satisfaction of occupants. Specific points about the objectives, the factors and the methods are made in the following subsections.

6.1 Objectives

In both questionnaires respondents clearly felt that the objectives of lighting controls were to meet the needs of the users of the lights and to reduce the costs for lighting. With the second questionnaire, respondents generally indicated that there was little if any difference between the objectives for the open-plan office and the elementary school classroom. Even for the retail store user, related objectives were consistently perceived as the most important objective and 'conserve natural resources' and 'low intial costs' were always the least important objectives. In general then, the respondents' objectives for lighting control were nearly the same for these three different kinds of spaces.

6.2 Factors

Consistent with the objectives, the factors seen as important to lighting control in the first questionnaire were generally associated either with costs, such as utility bills and operating budget, or the user, such as hours of use or type of task performed. Other important factors that respondents listed were past experience, architectural appearance, type of light source, security and safety. Some respondents to the first questionnaire indicated that the factors had to be delineated before it was possible to make a proper assessment of the methods for controlling lighting. In the second questionnaire important factors to be considered in the three examples of building spaces were listed, to guide the respondents in describing the methods for lighting control.

6.3 Methods

There was considerable variation in the methods chosen to control lighting in the two surveys. For instance, with the open-plan office, the 300 respondents gave 144 different patterns of responses to the matrix shown in Table 11. The variation was largely caused by different choices in automatic options. (Of the automatic options chosen, automatic timed switching was the most popular; many also felt that photoelectric dimming and switching should be considered).

In general though, respondents opted for a mixture of manual and automatic control methods. They also indicated that both local and central controls were important in the design of the lighting control system.

The respondents apparently felt that people should have local manual control over the lighting ('meet the user's needs'), but were dubious about the user's ability to consistently regulate the lights to prevent wasted energy ('reduce the net operating costs'). Thus, there was a perceived need to augment local manual switching with centralized automatic 'fail safe' features. The automatic options chosen to control the lighting were largely the result of individual inclination.

7. ACKNOWLEDGEMENTS

The authors would like to thank those who took part in the surveys, Professor R. Dillon and Mike Ouellette for their assistance with the data from the second questionnaire, and finally the Canadian Electrical Association for its sponsorship of the Industrial Fellowship. This paper is a contribution from the Division of Building Research, National Research Council of Canada, and is published with the approval of the Director of the Division.

8. REFERENCES

Lowry, R., and Rea, M.S., Energy conservation through lighting controls, Lighting Design & Application, 11, 9, September, 1981, 33.

Verderber, R.R., and Rubinstein, F.M., Lighting controls: survey of market potential, Energy, 8, 6, 1983, 433. (Lawrence Berkeley Laboratory Report LBL-11209 Berkeley, CA.).

LIGHTING CONTROLS: The Role of Advanced Technology- Past, Present, and Future

R.R. Verderber and F. Rubinstein

ABSTRACT

The role of technology in the development of lighting control systems is examined. Prior to 1973, control systems were primarily functional. They were used to switch lamps on and off, or to create a mood. Nearly all dimming was done with incandescent lamps.

Since 1973, the rising cost of electrical energy has made the operational cost of systems a design factor. Lighting controls are used to decrease power, reduce the time of use, and lower peak power demands. New lighting control equipment is based on existing technologies that have been modified to meet the needs of lighting systems. The technologies came primarily from the field of electronics.

These developments have made it technically feasible to automatically control the intensity and distribution of lighting in an area illuminated by a single fixture. These technologies form the basis for meeting future goals of lighting designs to alter illumination levels over time.

CONTRÔLE DE L'ÉCLAIRAGE: Le rôle de la technologie de pointe - le passé, le présent, le futur

R.R. Verderber et F.M. Rubinstein

RÉSUMÉ

Le rôle de la technologie dans le développement du contrôle de l'éclairage est examiné. Avant 1973, les systèmes de contrôle remplissaient principalement une fonction pratique. Ils servaient à l'allumage et à l'extinction des lampes ou encore à créer une ambiance. La gradation de lumière était presque toujours réalisée au moyen de lampes à incandescence.

Depuis 1973, en raison de l'augmentation du coût de l'électricité, les coûts operationnels de l'éclairage sont devenus un facteur de conception. Le contrôle de l'éclairage est utilisé pour réduire la puissance, la durée d'utilisation de l'éclairage et la demande de puissance de pointe. Le nouvel équipement de contrôle de l'éclairage s'appuie sur les technologies existantes qui ont été modifiées dans le but de satisfaire aux exigences de l'éclairage. Ces nouvelles technologies sont principalement issues du domaine de l'électronique.

Les progrès réalisés ont rendu techniquement possible le contrôle automatique de l'intensité et de la distribution de l'éclairage dans un local doté d'un seul luminaire. Ces technologies serviront à atteindre les objectifs futurs de conception visant à modifier les niveaux d'éclairage au cours d'une période donnée.

Dr. R. R. Verderber
Lighting Systems Research
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

ABOUT THE AUTHOR

Rudolph R. Verderber received the B.S. degree in physics from Syracuse University, Syracuse, NY, the M.S. degree in physics from Florida State University, Tallahassee, and the Ph.D. degree in solid-state physics from the University of Lancaster, England.

He has been involved in the study of the solid state, charge transport through thin films and di-electrics and the physics of devices. In the past ten years he has also been concerned with technology transfer and the commercialization of new concepts. He joined Lawrence Berkeley Laboratory in 1977 as a Staff Scientist and has been the Program Manager of the Department of Energy's National Lighting Program. In this capacity he has been involved in the development of solid-state ballasts for gas-discharge lamps, efficient lamps to replace incandescent lamps, and studies on lighting-energy management systems. Much of this effort has entailed the management and design of large-scale demonstrations of systems.

L'AUTEUR

Rudolph R. Verderber est détenteur d'un baccalauréat en physique de l'Université de Syracuse, d'une maîtrise en physique de la Florida State University de Tallahassee et d'un doctorat en physique de l'état solide de la University of Lancaster en Grande Bretagne.

Ses travaux ont porté entre autre sur le transport de la charge par des pellicules minces et des diélectriques et la physique des dispositifs. Au cours des dix dernières années il s'est également consacré au transfert de la technologie et à la commercialisation de nouveaux concepts. Il s'est joint au Lawrence Berkeley Laboratory en 1977 en tant qu'agent supérieur de recherche et a occupé le poste de directeur du National Lighting Program (U.S. Department of Energy). A ce titre, il a participé à la mise au point des ballasts à semi-conducteurs pour les lampes à décharge dans un gaz, de lampes efficaces pour remplacer les lampes à incandescence et à des études sur les systèmes de gestion de l'énergie pour l'éclairage.

Francis Rubinstein
Lighting Systems Research Group
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

ABOUT THE AUTHOR

Francis Rubinstein is a staff scientist in the Lighting Systems Research Group at the Lawrence Berkeley Laboratory. He received the B.Sc. degree in Physics from the University of California at Berkeley and was photometric test engineer for a major lighting fixture manufacturer.

Mr. Rubinstein is responsible for the Lighting Controls Program at the Lawrence Berkeley Laboratory and was technical manager of two large-scale demonstrations of lighting control systems. He has published several papers on the theory and practice of lighting energy management in buildings.

L'AUTEUR

Francis Rubinstein est agent supérieur de recherche au sein du Lighting Systems Research Group du Lawrence Berkeley Laboratory. Il est détenteur d'un baccalauréat en physique de l'Université de Californie à Berkeley et a été ingénieur d'essai photométrique pour un important fabricant d'appareils d'éclairage.

F. Rubinstein dirige actuellement le programme sur le contrôle de l'éclairage du Lawrence Berkeley Laboratory et a été le directeur technique de deux installations servant à l'expérimentation à grande échelle des systèmes de contrôle de l'éclairage. Il a en outre publié plusieurs articles théoriques et pratiques sur la gestion de l'énergie requise pour l'éclairage des bâtiments.

INTRODUCTION

The increasing use of lighting control systems has been due to the need to reduce the energy consumed by the electrical illumination of spaces. This has resulted in the adaptation of existing technologies for controlling lighting. The various types of lighting control systems have provided lighting designers with new freedom for illuminating spaces.

This paper will discuss the attributes of these new technologies with respect to their present use. Based on the changes in the lighting design needs and objectives, we will discuss the future of these technologies.

Lighting controls cannot be discussed solely in terms of technological advances; we must consider other factors that have influenced their use. These factors include design philosophies and the economic environment.

PAST (PRE-1973)

A major change in application philosophy for lighting control systems occurred after 1973. Prior to 1973, the use of lighting controls was based on functional requirements. Lamps had to be switched on and off at or near the areas they illuminated. Special effects could also be achieved in stage lighting, theaters, and conference rooms by changing illumination levels.

TABLE I PRE-1973 LIGHTING CONTROL EQUIPMENT

EQUIPMENT	LAMP	RANGE OF CONTROL
Socket Switch	Incandescent; Gas-Discharge	on or off
Wall Switch	Incandescent; Gas-Discharge	on or off
Three-Way Switch	Incandescent	100,67,33,0%
Rheostat	Incandescent	100 to 0%
Variable Auto-transformer	Incandescent	100 to 0%
Solid-State Switch (Silicon-Controlled Rectifier, Triacs)	Incandescent	100 to ~10%
Phase Control with Magnetic Dimming Ballast	Gas-Discharge	100 to 30%

Table I lists some of the lighting control equipment and techniques in use prior to 1973. The on-off switches could be used for all types of lamps (incandescent, fluorescent and high-intensity discharge). The three-way socket was used in conjunction with a two-filament incandescent lamp and was popular in the home. The rheostat and variable autotransformer were used to control lighting in commercial and industrial applications. Dimming with a rheostat is inefficient since the reduced power to the lamp is transferred to the rheostat. The variable autotransformer was considerably more efficient in the transfer of supply power to the lamps. Both of these rather cumbersome analog controls were used to dim incandescent lamps.

In the 1960s, solid-state switching devices were produced by the semiconductor industry. The devices (silicon-controlled rectifiers and triacs) varied the duty cycle of the input power to a load. The alternating current switch (triac) was low-cost and dissipated very little power. These devices, which could dim incandescent lamps over a wide range, became popular for home use; they were also used in place of autotransformers in commercial applications.

Near the end of this era, special magnetic ballasts became available that could dim fluorescent lamps. They applied a suitably high-voltage pulse every half cycle to maintain the gas discharge as the power to the lamps was reduced. None of these innovations brought about a philosophical change in the use of lighting controls. The general lighting in commercial and industrial buildings was still manually controlled by a few centrally located switches on each floor.

PRESENT (POST-1973)

The year 1973 is a watershed in the use of lighting controls. There was not any extraordinary technological innovation at that time, but an oil crisis occurred that had monumental impact on the lighting industry. Reducing dependence on foreign energy resources became a national concern. The cost of electrical energy increased sharply, so the operating cost of lighting systems also jumped and became a significant expense for consideration in the selection of lighting equipment.

Table II lists the possible responses to the increasing operating costs of lighting systems: i) in many existing spaces illumination can be reduced; ii) lighting designs must better meet the new Illuminating Engineering Society (IES) recommended illumination levels; iii) light levels can be reduced for short periods of time to minimize peak power demand charges; iv) more efficacious lamps and lighting systems can be used; v) use of lighting can be reduced in sporadically unoccupied spaces and, vi) use can be reduced during peak demand hours when electrical energy charges are greater. Lighting controls, by the use of one or more of the strategies listed in Table III, play a role in five of the six means to reduce operating costs. The control equipment will have a relatively small influence on the efficacy of a lighting system. These strategies have been described in a previous report[1] that did not include load shedding. Load shedding does not significantly reduce energy usage though it minimizes peak power demand charges, thereby reducing operating costs.

TABLE II PRINCIPAL MEANS OF REDUCING OPERATING COSTS OF LIGHTING

Reduce excess light levels.

Meet recommended illumination levels.

Shed lighting loads, reduce peak demand charges.

Increase lamp, ballast, and fixture efficacy.

Reduce annual time of use.

Reduce time of use during peak demand hours.

TABLE III LIGHTING CONTROL STRATEGIES

STRATEGY	EFFECTS
Scheduling (predictable)	Annual Time of Use
Scheduling (unpredictable)	Annual Time of Use; Use at Peak Demand Hours
Tuning	Meets Recommended Levels; Reduces Excess Levels
Lumen Depreciation	Meets Recommended Levels; Reduces Excess Levels
Daylighting	Peak Demand Hours-- Reduces Excess Levels
Load-Shedding	Reduces Peak Demand Charges

Existing technologies, adapted for controlling light sources, have affected lighting control equipment introduced since 1973. Because the concern has been to reduce the operating cost of general lighting, the technologies have been directed at dimming gas-discharge lamps (mostly fluorescent lamps). These types of lamps are used in most commercial and industrial buildings; these buildings are used during peak demand hours, and lighting costs are a substantial portion (30 to 50%) of the operating cost of the buildings. The semiconductor SCR and triac devices developed before 1973 are still the preferred method of controlling incandescent lamps. The lighting control equipment and the more efficacous lamp systems both add to the initial cost of a lighting system. The economic justification for the increased initial cost must be based on an acceptable life cycle cost or payback period due to reduced operating costs.

Static Controls

The lighting industry's initial response to rising energy costs focused on the over-illuminated spaces in existing buildings. Table IV lists several types of products and concepts designed primarily for retrofitting such spaces. They can be generally characterized as low-cost, simple to install, and designed to reduce energy use by substantially reducing illumination levels. The table includes the concept of delamping--removing one or two lamps from three- or four-lamp fluorescent fixtures, respectively.

TABLE IV STATIC LIGHTING CONTROLS

EQUIPMENT/CONCEPT	CHANGE IN LIGHT LEVEL (%)
Delamping	50
Impedance Monitors	
Lamps	30, 50
Devices	30, 50
Energy-Saving Fluorescent Lamps	5 to 12
Non-CBM* Ballasts	0 to 25

* Certified Ballast Manufacturers

While the devices on the above list may differ from one's concept of a lighting control device, they all result in a semi-permanent change in light level.

Dynamic Controls

The devices listed in Table V are types of control components that can be used in automatic lighting control systems. They differ from the equipment on the static list in their ability to alter the lighting distribution in response to activities in a space. Each component will be briefly described with respect to its function and primary applications. The elements of a control system can be grouped under three functional categories: light controllers, sensors, and communicators. Light controllers are electronic devices that directly interact with lamps to turn them on or off and/or to obtain some intermediate light output. Sensors are devices that sense time, illumination levels, or occupancy of a space. The occupant is also designated as a sensor who provides an added sensitivity that the above physical sensors cannot. The communicators are elements of a control system needed to transmit information from the sensors to the lighting control. The information may have to be stored and compared to a set of stored prescriptive instructions.

TABLE V DYNAMIC LIGHTING CONTROLS

EQUIPMENT	RANGE OF CONTROL
Light Controllers	
Switches/Relays	on,off
Power Conditioners	100 to 50%
Solid-State Dimming Ballasts	100 to 10%
Sensors	
Clocks	seconds to annual
Photocells	3000 to 1 footcandle
Personnel	100 to 300 sq. ft.
Occupants	
Communicators	
Hardwire	
Radio	
Power-Line Carrier	
Data processor, storage	

Light Controllers

Relays--Lamps can be turned on and off by relays that control input power. Light controllers that switch power lend themselves to controlling branch circuits and are effective for performing centralized types of control strategies. That is, the degree of local spatial control is limited by the supply power circuits (distribution of the branch circuits). The relays can be combined with a clock and a storage system to control the operation of lamps based on a prescribed schedule. When centrally installed, the system is low in cost and particularly suitable for retrofitting spaces.

Power Conditioners--There are various types of electrical systems that can condition the input power to gas-discharge systems and alter their light output. These new systems have been developed so that the special magnetic dimming ballasts described previously are no longer required, i.e., they can dim fluorescent lamps operated with standard magnetic ballasts. Power conditioners either alter the duty cycle or the line voltage of the supply power. Since they are based on switching power, they too are most effective for controlling large groups of lamps (branch circuits) and for centralized types of control strategies. They control the light output over a continuous range of levels. Incorporated with a control system that includes a clock, photocells, and a storage system, a power conditioner system can perform up to three control strategies, including scheduling, lumen depreciation, and load shedding. Since these systems control many lamps and are centrally installed, their initial and installation costs are reasonably low.

Solid-State Dimming Ballasts--The solid-state dimming ballast is both a ballast and a light controller. This device operates fluorescent lamps at a high frequency, improving the intrinsic lamp-ballast system efficacy by 20 to 25%. The high-frequency operation of the lamps permits them to be dimmed over a greater range of light levels (100 to 10%) than most power conditioners (100 to 50%). The ballast can dim the lamps manually at the fixture or remotely via a low-voltage signal. Dimming is accomplished by modulating the ballast's internal circuit. Thus there are no basic cost advantages in either dimming a single fixture or a group of fixtures, as is the case where the control of power is required. If a ballast is used in conjunction with a clock, photocells, and an information processor, all five control strategies can be performed. Since this system includes the premium cost of a ballast that must be installed in each fixture, it has the highest initial cost (equipment and installation). This system is more cost-effective for renovation and new construction applications where the installation costs are minimized. Since this system permits control of single fixtures over a large range of light levels, it is the most technically advanced and will result in the greatest reduction in operating costs.

Sensors

Clocks--A timing device in a control system can be as simple as a mechanical clock that operates a switch to turn lights on or off. More sophisticated electronic clocks have memory to provide a daily schedule for the operation of the lighting system over an entire year.

Personnel Sensors--Infrared and ultrasonic transmitter/receivers can be used to sense motion in order to determine the occupancy of a space. Personnel sensors are packaged as systems that include light controllers. These systems can be used for areas as large as 400 square feet. This control technique is most effective for spaces occupied by only one person, when the amount of time the space is occupied is known. For more densely occupied spaces, the probability of the space being unoccupied (lamps off) decreases. Other preferable uses are in spaces that are frequently occupied temporarily by one person (e.g., copying machine spaces in offices). Since the amount of time a space is vacant is proportional to savings in the operating costs, these systems are best used in retrofits where the unscheduled activities in the space are documented.

Photocells--Photocells are used to measure the illumination levels in an area. One photocell can be used for a large area in the lumen depreciation strategy, which is centrally controlled and where only the illumination levels from the electric lights are sensed. A higher density of photocells must be used in conjunction with daylighting to sense the illumination levels from the daylight and electric lights. The output of the sensor must be amplified and can be sent directly to the lighting controller or it can be sent to a central processor that will command the appropriate lamps.

There are photocell lighting control systems available that are designed to control two to four lamps and that operate fluorescent lamps with conventional magnetic ballasts. While these systems are relatively expensive, retrofitting them in areas with considerable amounts of daylight renders them cost-effective.

Occupants--Most existing lighting controls are manually operated by occupants. In automatic systems, even with all of the sensing devices, there will be occasions when the lighting system will not meet the occupants' needs. Thus, automatic systems must provide some means to override the information from the automatic control system. These overriding commands can be accomplished with switches and/or over telephone lines.

Communicators

Hardwiring--Most lighting control communication links are hardwired from the sensor to the light controller or to the information processor. For centralized systems, where all the elements are in the same space (an electric closet), material and installation costs are small. For systems that have photocells and lighting controllers distributed throughout the illuminated space, hardwiring becomes more costly. For this reason, these systems are best used in renovations and new construction, where the wiring installation costs are minimized.

Power-Line Carrier--The communication signals can be sent over existing power lines. This eliminates the need for stringing communication lines and allows considerable flexibility in the modular control of spaces. However, the lighting information must be discriminated from the electrical noise on the power lines. The coding and decoding format becomes more complex as the number of independent communication stations (transceivers) increases. Power-line carriers are most cost-effective in retrofits with only a few communication stations.

Radio Links--There are some lighting control systems that link the sensor and the lighting controller via radio signals. The transmitters and receivers are costly and most effective in switching large power loads that are not easily accessible. The receivers must be made impervious to stray radio signals.

SUMMARY OF PRESENT

The need to reduce the operating cost of illuminating spaces has resulted in the development of technologies that can automatically turn lamps on and off, reduce lighting levels, and reduce the time of use. Table VI lists six technologies that were initially developed for applications other than lighting systems.

TABLE VI TECHNOLOGIES ADAPTED FOR USE IN LIGHTING CONTROLS

TECHNOLOGY	APPLICATION: INITIAL	APPLICATION: LIGHTING
Motion Sensors	Burglar Alarms	Occupancy Sensors
Switching Power Supply	DC Supplies for Computers	Solid-State Dimming Ballasts
Radio Transmission	Garage Door Openers TV Channel Changers	Communication Links
Power-Line Carrier	HVAC Control, Home Applications	Communication Links
Computer/Microprocessor	General Data Processing, Energy Management Systems	Lighting Management Systems
High-Power Semiconductor Switches	General Control of Duty Cycle of Power	Lighting Controllers

These technologies had to be amended for lighting applications. Typical for most initial applications of new technologies, the unit costs of the equipment could be high and the volume density low. Generally, lighting equipment has a relatively high density of units in space and unit price must be minimized. In addition, lighting systems are installed in many uncontrolled environments. This requires the equipment to operate reliably at very hot and cold temperatures as well as to withstand line surges.

The initial applications provided in the table are examples of the less stringent requirements for these technologies; burglar alarm systems cost thousands of dollars, the transceiver/transmitter need control only one control point; d.c. switching supplies for computers are in conditioned environments. Automatic lighting control systems require communication between many sensing and control points to increase the effectiveness of the systems to meet the varied activities in a space. The fact that all the lighting control equipment described has found some use indicates that these technologies have been suitably amended to meet some of the stringent requirements for lighting.

The relatively few automatic lighting control installations that have been monitored have demonstrated some significant technical and economic achievements. Table VII lists eight major achievements that have been realized by the lighting controls industry. There has been a considerable reduction in cost in the equipment adapted for lighting. Several on-site demonstrations[2-5] of different types of control equipment have documented large reductions in operating cost through energy savings. The achievements related to dynamic lighting design include: the ability to independently control light output of single

fixtures, to control illumination in sectors independent of the supply power layout, and to alter the illumination for unpredictable events in the space. It is almost fortuitous that an oil crisis occurred, since, as a result, a host of new equipment has been developed and applied that has provided lighting designers with additional degrees of freedom to implement the most sophisticated concepts for illuminating spaces.

TABLE VII LIGHTING CONTROL ACHIEVEMENTS

Lowering equipment costs of initial technologies.

Providing large decreases in operating costs.

Providing yearly automatic schedules for building illumination.

Maintaining specified illumination levels through lives of lamps.

Providing control of maximum light output of single fixtures.

Providing means to shed loads on a priority basis.

Controlling lighting for unpredictable schedules.

Eliminating the need for hardwired communication links.

FUTURE

The goals and aspirations of the lighting community have continually grown due to its increased understanding of the needs of occupants with regard to visual acuity and comfort. Recommended levels are continually reviewed by the IES committees. Metrics of quality have emerged: visual comfort probability (VCP) and equivalent sphere illumination (ESI) and are employed in the design of lighting layouts. Table VIII lists other factors that presently affect or are emerging concerns in determining how spaces should be illuminated. If the goal of the lighting profession is to provide the proper level of illumination with optimum quality suited to the occupant of the space and the task, it should be evident even to the uninitiated (non-lighting-designer) that this cannot be achieved with static, dedicated lighting systems. Each of the items listed in Table VIII can only be achieved by altering the amount and the distribution of the illumination after the space has been furnished and occupied. For example; it is unreasonable to expect the lighting designer to know the occupants' ages or the speed and accuracy requirements of their tasks. Changes in the electrical illumination levels and distribution are required over relatively short periods for changes in the occupant's schedules, when daylighting is employed and when the specified light levels are maintained.

TABLE VIII SOME ISSUES THAT HAVE EMERGED RECENTLY

The expanded use of open office space.

The common and growing use of video display terminals.

The latest IES recommended light levels as related to:
- Age
- Speed, accuracy
- Task reflectance
- Room surface reflectances

The desire to improve quality of illumination.

Recognition of the limitations on the accuracy of computer programs.

Manufacturers' tolerances of equipment.

Providing and maintaing specified lighting levels through time.

Use of daylight for illuminating spaces.

Adapting illumination to the rearrangement of spaces and visual tasks.

Based on an attempt to meet the above goals and the concerns that face the lighting community, the necessary advances in lighting controls technologies will be discussed. The projected, necessary advances are listed in Table IX. The first two, reduced cost and reliability, are self-evident. In order to be universally used, equipment cost must further be reduced. While some reduction can be expected due to increased volume, improvement in the technologies are necessary.

TABLE IX NEEDED TECHNOLOGICAL ADVANCES

The following advances to equipment are needed:

Reduced equipment cost.

Improved equipment reliability.

Development of scanning photocells.

Development of scanning personnel sensors.

Installing a transceiver in each electronic ballast.

Developing a power-line carrier system for high-density control points.

Developing a lighting management system compatible with building energy [illegible]ement.

Photocell

A single photocell measures the average illumination over an area that is used to determine the illumination over a space. For the lumen depreciation strategy, the illuminated space is considerably greater than the area measured by the photocells. In order to suitably apply the daylight strategy, the measured area must be about the same area of the illuminated space. This requires a relatively high density of photocells, about one per 150 square feet. If a photocell can be developed that can scan a large area and provide the illumination information for local areas, one such photocell can be used for daylighting open office spaces. This can reduce the need for many photocells and communication terminals. With the new device, all of the illumination information for the room can be obtained from one point.

Personnel Sensors

The limitation to personnel sensors has been the relatively small area of their effectiveness, resulting in the control of a small amount of power, 200 to 300 watts. If a scanning personnel sensor can be designed to scan larger areas, it could be a more effective tool for large spaces, in particular for the open office spaces that are now in vogue. This would also reduce the number of sensing sites throughout the space.

Solid-State Dimming Ballasts

In the course of developing solid-state ballast technology, it should be possible to include a transceiver in each dimming ballast. With this capability it would be possible to communicate automatically with each ballast/lamp unit independently of the other systems on the floor. It would permit one to establish a multitude of lighting patterns that would reflect the arrangement of the office space. Such a system would offer the lowest operating cost for the optimum quality and quantity of illumination.

Power-Line Carrier

With the above solid-state dimming ballast innovation, the development of a power-line carrier system that can communicate without error and with a multi-channel system would permit optimum flexibility. The illumination system would be totally independent of the supply power circuit. In addition, any necessary changes in the illumination intensity or distribution could be executed rapidly at virtually no cost via a simple change in the computer program. A many-channel system would be technically feasible today if there were no noise on the line. An error-free system must be developed that is not susceptible to the ambient noise on the line or in the space.

Lighting Management System Capability

The final development is the integration of the lighting management system with the building management system. Today there is increasing use of energy management systems for the HVAC control of buildings. Some of these systems include some simple management of the lighting system. The building management systems have relatively few control points, resulting in a high cost per control point. Lighting management systems require many control points and, for a cost-effective system, the cost of each control point must be less. If a system can be designed to compensate for these different needs, a total building system can be designed to be more cost-effective, since the same computer system can be employed to control nearly 90% of the building's energy usage (HVAC and lighting) to optimize its total energy performance.

SUMMARY

The present need to reduce the operating costs of lighting spaces has resulted in the adaptation of technologies to control lighting systems. The new lighting equipment has had a profound effect on lighting designs by permitting changes in intensity and distribution of illumination after a space has been furnished and occupied. This has permitted the lighting system to be tuned to the visual needs of the occupants for the system's entire life.

Realization of the power of the lighting management system in optimizing of the illumination of a space indicates that such systems should be universally employed. This requires further development of the equipment that have been introduced during the past 10 years. The targets include lower cost, more reliable components, and the integration of the lighting with the building management systems.

It is interesting to note that, in the past and present, lighting controls have reflected lighting needs. However, the future of lighting control equipment and systems will be predicated on the technological advances that have shown the potential for automatically providing the type of lighting that can best approach the IES goals for illuminating spaces.

ACKNOWLEDGEMENT

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Energy Research and Development, Buildings Equipment Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

REFERENCES

1. Verderber, R.R. and Rubinstein, F.M. Lighting controls: survey of market potential. Energy 8, No. 6 (1983), p. 437

2. Turner, O. Occupancy controlled lighting: energy savings demonstration and analysis. NYSERDA Report, 255/EV-RCV/80, 82-33, May 1982.

3. Verderber, R. R., et al., Energy savings with solid-state ballasts in a Veterans Adminstration medical center, IEEE Transactions on Industry Applications IA-78, No. 6, Nov-Dec 1982, pp. 653-665.

4. Freund, A., ed. Superior office lighting, an unusual approach. Electrical Construction and Maintenance, 82, No. 11, Nov. 1983.

5. Rubinstein, F. M., et al., Field study on occupancy scheduling as a lighting management strategy, Lighting Design and Application, 14, No. 5, May 1984, pp. 34-45.

LIGHTING CONTROL:
Impact on Energy

V.H.C. Crisp

Abstract

This paper briefly reviews studies of occupant control of electric lighting with traditional manual switching arrangements. The understanding gained from these studies permits the development of a general strategy for improved lighting controls that can lead to substantial energy savings, particularly for multi occupant spaces which benefit from some daylighting.

The types of control required to implement the control strategy are outlined and some examples of their use, drawn from monitored installations in the UK, are described.

CONTRÔLE DE L'ÉCLAIRAGE:
Impact sur l'énergie

V.H.C. Crisp

Résumé

On examine brièvement dans cette communication les études effectuées sur le contrôle de l'éclairage par les occupants au moyen de systèmes d'allumage et d'extinction manuels courants. Les résultats de ces études permettent d'élaborer une politique globale visant à améliorer les techniques de contrôle de l'éclairage. Ces améliorations peuvent se traduire par des économies substantielles d'énergie, particulièrement dans les locaux à occupation multiple qui bénéficient de la lumière du jour.

Les types de contrôle requis pour l'implantation d'une politique de contrôle sont également examinés; des modèles de leur utilisation actuellement à l'essai dans des bâtiments en Grande-Bretagne sont décrits.

Dr. V.H.C. Crisp
Head of Lighting Section
Mechanical and Electrical Engineering Division
Building Research Establishment
Department of the Environment
Garston, Watford, WD2 7JR
U.K.

ABOUT THE AUTHOR

Dr. Crisp joined the Building Research Establishment in 1973 following post graduate and post doctoral work in solid and liquid state metal physics at the University of East Anglia (UK), and became head of the Lighting Section in 1978. He is a member of the Chartered Institution of Buildings services and serves on its Council and Technology board as well as its Lighting Division Technical Committee and various panels concerned with Daylighting, Discomfort Glare, etc. He represents BRE on the National Illumination Committee of Great Britain (National Committee to the Commission Internationale de L'Eclairage) and is a consultant to several CIE Technical committees.

L'AUTEUR

Après avoir terminé des études universitaires supérieures et post-doctorales en physique des métaux à l'état solide et liquide à l'université East Anglia (G.B.), V.H. Crisp s'est joint au Building Research Establishment en 1973 et occupe le poste de chef de la section de l'éclairage depuis 1978. Il est membre de la Chartered Institution of Building Services et participe aux travaux du Council and Technology Board et du Lighting Division Technical Committee de cet organisme, ainsi qu'à divers groupes de travail sur la lumière du jour, l'éblouissement gênant et autre. Il est également le représentant du BRE au National Illumination Committee of Great Britain (Comité national de la Commission internationale de l'éclairage) et agit comme consultant auprès de nombreux comités techniques de la CIE.

1. BACKGROUND

1.1 ENERGY USED FOR LIGHTING IN BUILDINGS. On a national basis, the consumption of energy used for lighting is more modest than the attention it attracts often seems to merit. In the UK for example it represents some 5% of the total energy use [1], a figure similar to that for North America, although in the latter case lighting accounts for a rather larger share of electricity use than in most of the developed world [2]. However, for non domestic buildings, lighting can account for a very substantial proportion of energy usage and, for example, in offices may be responsible for more than half the cost of maintaining a habitable internal environment [1,3].

It has often been pointed out that because salary costs, in general, dwarf building operating costs for most organisations, then efforts to trim lighting energy costs - which may inadvertently and adversely affect productivity - are misplaced. In a sense the point is well made since the productivity 'lever' is large, but it presupposes that reducing energy used for lighting necessarily results in a less productive visual environment. It is contended below that the use of appropriate lighting controls can be both conducive to energy efficiency and the provision of a suitable environment: indeed may improve occupant perception of that environment. Furthermore, because energy costs are often one of few of the total operating costs that can be independently manipulated, a reduction in energy consumption feeds directly into the profit margin - indeed the two factors are often similar in size in monetary terms.

1.2 TRADITIONAL CONTROL ARRANGEMENTS AND THEIR IMPACT ON LIGHTING USE. The potential impact of the use of recently developed lighting controls can only be assessed relative to traditional control arrangements. In the UK and to a slightly smaller extent in North America the overwhelmingly predominant method of control has been the manual mains switch and equally important, its disposition in the lit space has almost invariably been close to the entrance to that space. Rarely has lighting control been distributed within internal spaces and it has not been totally uncommon for whole floors of large buildings to have only a single switch for all luminaires.

Since much of the present building stock was constructed during an era of relatively cheap energy the lack of built in switching flexibility can be understood in terms of the desire to reduce installation costs. Subsequent profligate use of lighting can often be explained simply in terms of minimal switching arrangements ie a single switch in a multi-occupant space gives no latitude for discriminating use. However, similar apparent use of lighting in interiors 'blessed' with multiple switches gave rise to the very common view that occupants could not be relied upon to use lighting economically eg by taking advantage of daylight - a view still widely held and one that can lead to a control solution that is wholly automatic.

In a series of studies carried out by BRE, an alternative model of occupant behaviour emerges, which gives scope for a more imaginative

range of control regimes which can often include the occupants of the building as active and beneficial elements of the control system. The studies were carried out using direct observation by time lapse photography and took place in a range of school and office interiors. The interiors were multi-occupant and all had their lighting controlled by manual switches mounted on multi-switch panels located by major entrances/exits to the spaces. The major conclusions can be summarised very simply:

1. Usually either all or none of the lighting was in use - it was rare for only a part of the lighting to be on.

2. The occupancy cycle of the space determined when people switched the lights on and off. Lights were switched on (if needed) when people entered a space, but rarely switched off until the space became completely empty. Thus in continuously occupied spaces, such as multi person offices, switching was generally confined to the beginning and end of the working day (Fig 1A). By contrast in intermittantly occupied spaces, such as school classrooms, switching occurred throughout the day (Fig 1B). Clearly these distinct patterns of switching activity resulted in quite different profiles of overall lighting use with time of day and daylight availability. (Fig 2A and 2B).

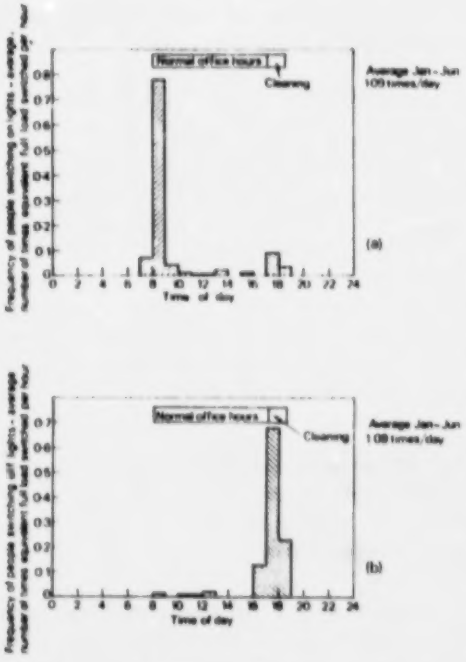


Fig 1A. Switching activity in a continuously occupied multi-person office
(a) switch-on's
(b) switch-off's

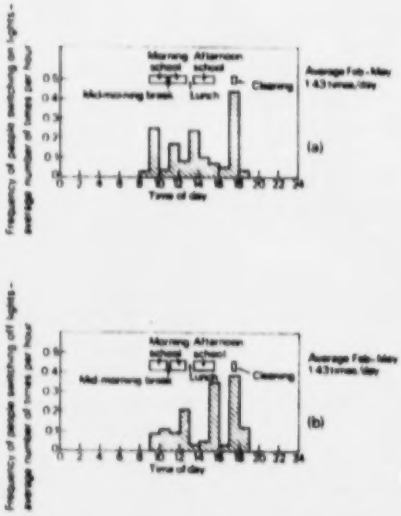


Fig 1B. Switching activity in an intermittently occupied school classroom
(a) switch-on's
(b) switch-off's

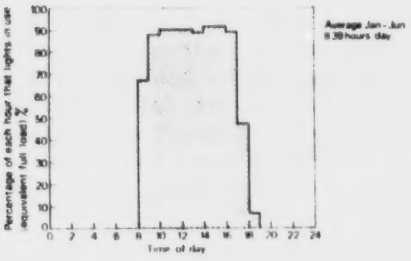


Fig 2A. Frequency of lights being in use, by time of day - multiperson office

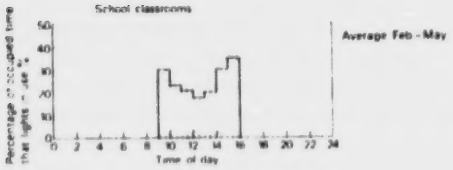


Fig 2B. Frequency of lights being in use, by time of day - school classroom
NOTE: Data omitted for any hour during which classroom occupied for less than 15% of the hour

3. The probability of people switching on the artificial lighting in a daylit space at the beginning of a period of occupation, was closely related to the minimum working plane daylight illuminances[4] (Fig 3).

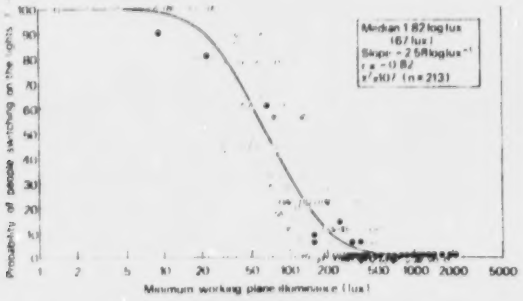


Fig 3. Probability of people switching on lights in relation to minimum daylight illuminance on the working plane NB Different symbols for different rooms studied

These conclusions represent a very simple model of occupant switching behaviour ie that a decision - not necessarily a conscious one - is made about daylight adequacy on entering a space and lighting switched accordingly. For traditional switching arrangements, that adequacy was judged, apparently not by the appearance of the particular occupant's work area, but was best correlated with the worst daylit area in the room (3 above).

The model is of course consistent with the view that the benefits of daylight are often effectively wasted. The explanation, however is not that occupants are necessarily unreliable and wasteful, but that at normal times for the start of occupation, daylight availability is relatively scarce. At a time when daylighting is enjoying a revival the implications of the above are of considerable significance, since the behavioural model indicates that daylight will not necessarily be employed as an alternative to electric lighting merely because it is available. Rather, the interplay of occupancy pattern and daylight availability at the beginning of occupation periods, dictate to what extent daylighting is effectively used. Indeed a consideration of the two factors - occupancy pattern and daylight availability - can be used to provide strategic guidelines for the energy efficient application of lighting controls.

2. STRATEGY FOR CONTROL

2.1 OBJECTIVES TO BE MET. It is almost self evident that the major cause for the current interest in lighting control is the desire to reduce lighting energy costs following the relative increase in such costs a decade ago. Prior to that time only a few installations of, for example, automatic photo-electric switching, existed, but the subsequent world wide demand for energy efficiency has resulted in the birth of a modest but active and growing industry devoted to different lighting controls. Almost inevitably there is a cost associated with the more efficient use of lighting, so that our first objective should not be seen merely as the quest for energy efficiency but resource cost efficiency ie the balancing of reducing energy costs against extra capital and installation costs and implied committment to recurrent maintenance costs.

Inevitably different organisations will analyse this balance in different ways using, for example, simple payback, life cycle costing or internal rate of return [5]. It is beyond the scope of this paper to discuss these different analyses but it should be borne in mind that any inferences drawn on the energy impact of controls are necessarily part of a broader equation.

The second broad objective for controls, which cannot be wholly divorced from energy considerations, is the provision of acceptable conditions for the occupants of the spaces whose lighting is to be controlled. As has been alluded to above (1.1) and discussed in detail by Peter Boyce in his paper, the saving of energy and hence cost will be to little avail if occupants' conditions are degraded to the detriment of their performance.

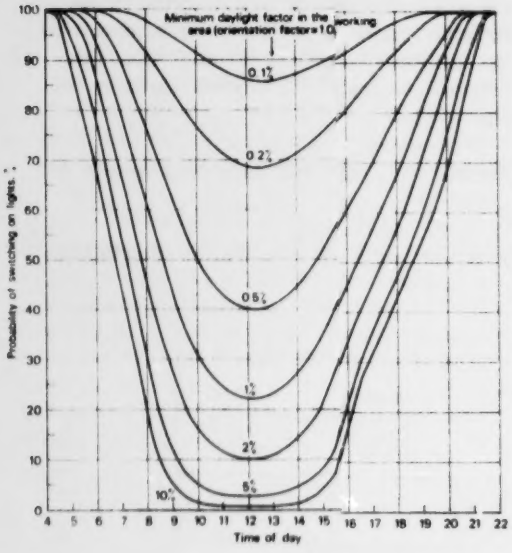
2.2 THE FACTORS AFFECTING THE FORM OF CONTROL. If the behavioural model associated with manual switching outlined briefly above (1.3) has validity then the major factors affecting lighting use are occupancy pattern and daylight availability.

It follows that the major factors to be accounted for by any proposed control of lighting should also be occupancy pattern and daylight availability.

Beyond these factors, however, safety and security will necessarily influence the final control system. Although it is difficult to give general rules for all situations, there will always be a requirement to ensure that appropriate and sufficient lighting can be operated independently of any automatic control to enable safe access for normal occupants or security staff.

2.3 GUIDELINES FOR CONTROL. Using the occupant switching probability function (Fig 3) and external daylight availablity data, curves of the type in Figure 4 can be derived [6]. Although strictly only applicable to the UK the general features of the figure are instructive. Note the very much higher probabilities of switching on for normal occupation start times (early morning), compared with say, immediately post lunch time.

This implies that if a lunch time switch off is imposed, the lower probability of switching on when occupants return after lunch will result in immediate savings.



NB. Daylight factor is a function of window size and position and interior reflectances. It can be measured or predicted., eg. BRE digests 41 & 42. (Available from BRE Distribution Unit, BRE, Garston, Watford WD2 7JR UK)

Orientation factors for the daylight factor
S - facing windows 1.20,
N - facing windows 0.77,
E - facing windows 1.04,
W - facing windows 1.00

Fig 4. Switching probability related to time of day and daylight factor

Further, if manual switching arrangements are distributed throughout the space and related rationally to daylight penetration and local areas served, we can hypothesise that local switching will be related to 'local' worst daylight areas rather than a 'whole space' worst daylight area. (This assumes the model outlined in 1.3 can be extended to conditions outside those encountered in the original field experiments that led to the model. Studies by Boyce give support to that assumption [7]).

Necessarily this means that, on average, lighting will be less likely to be switched on and it may be that the convenience of the distributed switching will result in some switching off; although this is not necessary to obtain energy savings.

In effect the above defines a general strategy for control for interiors which benefit from daylight. That is centralised (and automatic) switching related to known overall occupancy patterns (time switching or scheduling) allied with local convenient (manual) switches available to occupants. Such a strategy can be enhanced by

automatic daylight linking or occupancy linking depending on the type of occupancy of the particular spaces. Table 1 provides a proposed set of preferred system options for different types of occupancy. In general it can be seen that the more 'tied' occupants are to their work area, the more automatic the overall system needs to become, because there will be fewer occasions for switching decisions to be remade by occupants ie on their departure from or return to the work-place. Clearly in very deep spaces or windowless interiors, the control options available are reduced. Nevertheless, the application of controls should be seen as recognition of:

a. the importance of occupancy patterns to lighting use and hence potential savings; and

b. the ability to take much greater advantage of available daylight than is otherwise likely.

INSTALLATION TYPE \ CONTROL OPTION	CENTRAL TIME SWITCHING	LOCALISED (ie DISTRIBUTED) SWITCHES - CONVENIENT TO OCCUPANTS	AUTOMATIC PHOTO-ELECTRIC DAYLIGHT LINKING	AUTOMATIC OCCUPANCY LINKING
MULTI-OCCUPANT VARIABLE OCCUPATION				1
MULTI-OCCUPANT ESSENTIALLY FULL OCCUPATION			2	
MULTI-OCCUPANT, INTERMITTENT BUT SCHEDULED OCCUPATION				1
ONE OR TWO OCCUPANTS (ESSENTIALLY CELLULAR) VARIABLE OCCUPATION				
ONE OR TWO OCCUPANTS (ESSENTIALLY CELLULAR) ESSENTIALLY FULL OCCUPATION				
LIMITED & INTERMITTENT OCCUPANCY				

Notes:

1. Only consider off switching with demand on (at present available systems are both on and off automatically).

2. Particularly attractive option for roof lit factory spaces where full dimming can be cost effective. Restrict P/E switching to luminaires near windows unless multi lamp multi level switching is practicable.

Key: recommended; probably worthwhile; Assess for particular installation

Table 1 Summary of control options for types of occupancy

It is also important to emphasise that in this general scheme the user can be an important part of the overall control system. Appropriate hardware elements can be seen to provide the opportunity for the lighting users to reassess their need for electric light either at times when, or positions where, their perception of daylight adequacy will necessarily be enhanced. (Time switching and localised switching). If the occupancy pattern is such that this cannot be done, then more automatic means of harnessing daylight may be called for (daylight linked switching or dimming). Where daylight is essentially absent controls can only eliminate lighting use at times when occupants are absent (time switching or occupancy linked switching) or permit occupants to modify their own conditions (localised switching).

The provision of controls that enable occupants to have some influence on their local conditions ie convenient localised switching, is important both from the energy standpoint (as outlined above) and as a positive aid to user satisfaction. Although it is difficult to justify the assertion in any quantitative manner, experience of a number of installations of controls indicates that the facility to control the local environment is positively appreciated by most occupants and goes some way to providing acceptance of any automatic element of the overall control system.

2.4 ESTIMATING SAVINGS FROM THE DIFFERENT CONTROL OPTIONS. The generic types of control have been outlined above and discussed in detail by Rudy Verderber. Below, the methods for estimating potential savings from these controls are outlined. The data referred to are strictly only applicable to the UK but in principle similar data could be prepared for North America.

Estimation of savings requires both a prediction of consumption with the controls and an estimate of use under existing conditions (for existing installations) or of use with traditional switching arrangements (for new installations).

2.4.1 LIGHTING USE UNDER TRADITIONAL MANUAL CONTROL. The basis for estimating use of lighting under traditional manual control is given in Fig 4. It gives an estimate of the probability (averaged over a working year) of electric lighting being switched on at the start of a period of occupation as a function of time of day and the available daylight, characterised by the minimum daylight factor in the working area. With a knowledge of the likely occupation pattern of given space an estimate of working year consumption is simply obtained.

2.4.2 TIME SWITCHING. If switching is controlled on and off, the estimated use is derived directly from the proposed schedule. If switching on is by demand but switching off is time-controlled, Fig 4 can again be used. The probabilities for switching on after automatic switch off (at lunch-time for example) are calculated along the same lines as before and overall use computed from these probabilities (weighted by appropriate periods from the time switching schedule).

2.4.3 LOCALISED SWITCHING. Fig 4 can be used but switching probabilities need to be obtained for each zone (controlled by separate switch). Overall use is then obtained by weighting these probabilities by part loads in each zone and summing for the complete installation. If occupancy is variable or intermittent, further weighting is carried out according to assumptions about occupancy.

2.4.4 DAYLIGHT LINKING BY PHOTOELECTRIC ON/OFF SWITCHING. Fig 5 [6] shows the percentage of a working year (assumed to be 0900-1730 hr daily) that a photoelectrically controlled lighting installation would be switched off as a function of the design illuminance of the electric lighting and daylight factor (orientation corrected). Departures from the standard day of up to one hour either way at each end of the day have little effect. The daylight factor should be calculated for the depth from the window wall at which the controlled lighting is situated and the predictions assume that the control will be calibrated to switch at the design level required. Consumption is simply obtained from the proportion of the working year that lights will be on multiplied by the lighting load controlled. For multizone control, a calculation is required for each zone.

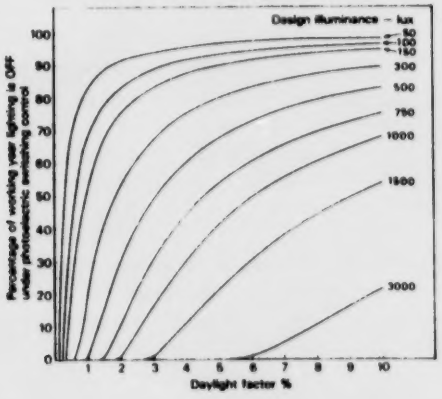


Fig 5. Gross energy saving from on/off photoelectric control for standard working year (09.00-17.30 h, BST April-October inclusive). Variation with Daylight Factor

2.4.5 DAYLIGHT LINKING BY PHOTOELECTRIC DIMMING (TOP-UP). Fig 6 [6] shows the percentage of the working year (again assuming 0900-1730 hr daily) for which the equivalent full load would be off using a phtoelectrically controlled dimming system. This takes into account periods during which output from the lighting is less than maximum - hence the term 'equivalent full load'. The curves are for different design illuminances as functions of orientation-corrected daylight factor. In constructing the curves, an assumption has been made concerning the energy consumption of the ballasts required for dimming. The assumption is based on measured performance of a dimming system and can be

assumed to apply to well designed systems. Calculation of consumption is the same as under Photoelectric on off switching.

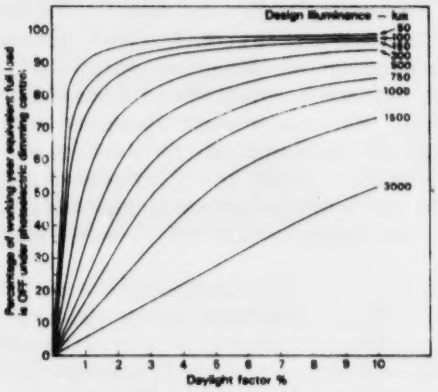


Fig 6. Gross energy saving from top-up photoelectric control for standard working year (09.00-17.30 h, BST April-October inclusive). Variation with Daylight Factor

2.4.6 OCCUPANCY LINKING. As for localised switching, an assumption must be made about the expected occupancy pattern of the given space; for automatic on and off occupancy switching, an estimate of consumption follows directly from that assumption. For automatic off only, with local demand on, the calculation of consumption needs to take into account probabilities of switching on (Fig 4) following an automatic off, according to the assumed occupancy pattern.

A saving in energy used for lighting may also lead to savings associated with air conditioning or, conversely, an increase in energy required for heating. It is outside the scope of this paper to examine this interplay in detail but it should be noted that, provided appropriate controls are present, overall energy efficiency will be greatest when lighting is not used to offset heating requirements.

2.5 EXAMPLES OF ENERGY CONSEQUENCES OF LIGHTING CONTROLS

It should be clear from above that it is impossible to give a unique for even simple answer to the question of how much energy might be saved by the application of lighting controls. Potential savings are intimately related to the occupancy pattern of the installations in question and hence to the type of work carried out, as well as to the degree to which available daylight can be harnessed. However, the examples described below give some indication of the scope of applications that exist.

Early case studies undertaken in Property Services Agency (PSA*) building's have been reported elsewhere (see Symposium bibliography). The results quoted below are all taken from projects which have been monitored as part of a scheme funded by the UK's Department of Energy (The Energy Conservation Demonstration Project Scheme). The scheme seeks to provide robust exemplar data for potential users of energy conserving technology, in order that their investment decisions can be made with confidence. The Department sponsors the demonstration of a particular technology at an applicant's premises with a grant of up to 25% of capital and installation costs. Further, the monitoring of the performance of the technology by an independent organisation is wholly funded through the scheme and the results made available in the public domain [8].

Over the 200 projects are proceeding within the scheme with more than 50 associated with the non domestic building sector. Of these approximately one half are concerned with energy management including lighting control. Some of the results of these projects are given below.

2.5.1 LOCAL GOVERNMENT CIVIC OFFICES - PORTSMOUTH [9]. The building consists of 24,400 sq.m of open plan office space arranged on six levels in the form of a staggered crucifix. Depth varies from 17-21 m with 100% tinted glazing on all facades. The lighting design level of 600 lux is achieved using fluorescent batten fittings mounted above a metal grid ceiling.

Original control was manual, using some 36 distribution boards distributed throughout the building (on the stairwells). Switching was carried out by security staff during the early morning and late evening rounds and resulted in an average use of 14.5 hours/day for the lighting.

The lighting control system chosen to replace this arrangement uses programmable relay units located near the distribution boards. (Each relay unit controls a bank of seven fittings). These units respond to time signals (generated by a central programmable controller and/or photocell signals (conditioned and routed by the central unit). Communication between the central unit and the relay units is by a low voltage signal bus and the relay units control the mains supply to the luminaires. The photocell element of control is designed to switch off electric lighting in the perimeter areas when daylight is sufficient to meet design level requirements. Time control is related to the gross occupancy schedule for the office and switches on as well as off. Manual override (to 'on' only) is provided at switch panels within each of the 25 open office areas. It must be said that these are not very close to many of the occupants but practical wiring considerations limited the number and desposition of such panels.

---

*PSA is the agency within the UK Department of the Environment responsible for the civil & defence estate. Is is similar to Public Works Canada, and is a major customer for BRE research.

Monitored savings achieved were 39%/annum ranging from 32% to 54% on a weekly basis. It was further estimated that some 5 to 6% more could have been saved by eliminating the early morning 'on' switch action, and requiring occupants to activate their own lighting at the switch panels.

2.5.2 LOCAL AUTHORITY CIVIC OFFICES - BRADFORD [10]. The building, of 7 storeys, has two wings providing a total of 15 open office areas. Each area measures some 41 m by 14 m with east and west facades glazed to about 55% of the window wall, with tinted glass. Lighting in each area is provided by 80 four lamp luminaires (to 750 lux) originally controlled manually from a switch panel located at each area entrance.

The control system installed uses a central programmable multi-channel time switch. This unit provides signals to a contactor (for each office area) to momentarily (1 sec) interrupt the mains supply to the lighting. Each luminaire incorporates a latching relay which latches to off on mains interrupt. Lighting can be restored by operation of an integral pull cord switch unit on each luminaire. Thus gross occupancy related switching is controlled by the central control unit and fully distributed localised overrides for occupants are provided by the pull cords. Full analysis of the performance has yet to be completed but interim results show a saving of 40% compared with pre-controls consumption.

2.5.3 COSMETICS PACKAGING HALL - NORTHAMPTON [11]. The hall, measuring 151 m by 45 m houses 34 separate packaging lines (parallel to the shorter wall) which are used to dispense measured quantities of various cosmetics into containers which are then closed, printed and packed into cartons. Each line has its own row of 15 luminaires each with 3 fluorescent lamps providing 450 lux in the packaging line area. The hall has no significant benefit from daylight and control of electric lighting originally consisted of a wall mounted switch plate at the end of each line. Lighting tended to be switched on at the start of the day (0800 hrs) and remained on until the evening shift finished (2300 hrs). The control system installed introduced time switching related to normal working patterns with overrides available at the existing switch panels. This was achieved by recircuiting such that 10, 30, 60 and 90% of the luminaires (on a row basis) could be independently controlled with each circuit 'patched' so that no area is totally without light even with 90% of the luminaires off. The switching off is then controlled by time switches eg at the beginning of lunch break (1230) 30% of lighting is switched off but available for resetting by the occupants; at the end of the dayshift (1715) 60% is extinguished etc.

The technology used (electro mechanical time switches, relays and low voltage cabling) is inflexible but suitable for the application. Savings have been monitored at 30% compared with use before controls were installed.

2.5.4 OFFICE BLOCK OF LARGE BANK - LONDON [12]. The office building is rectangular in plan with 15 floors of mixed open and cellular offices (office area per floor, 52 m x 15 m). The main facades are

north and south facing with approximately 60% double glazing (tinted on the south facade).

Lighting (to 500 lux) is provided by seven rows of recessed fluorescent luminaires parallel to the longitudinal axis of the building. The lighting controls were installed during the refurbishment of the building and the type of system used partly reflects a desire to minimise costs when reconfiguring internal partition walls. The control system consists of a local master control for each lighting module of 3 fittings (one in each row for each facade, the central row being independent and acting as 'corridor' lighting); a central control unit; and wall mounted or hand held infra red transmitting devices.

Overall time switching is achieved by programming the central control unit, which communicates to the local master controls via the mains wiring. Local control by occupants is by the infra red transmitters and local master controllers which contain an infra red receiver. Thus the hand held units are aimed at the receiver unit and actuated by button press (one for each luminaire); the wall mounted units being oriented towards the receivers and operated as wall mounted button switches. In addition, each local master unit incorporates a photocell which is used to control the perimeter luminaire in relation to daylight.

Monitoring has just been completed and the first six months data indicates a saving (compared with estimated use under traditional control) of almost 30% in lighting use.

3. CONCLUSIONS

The limited data presented above do not, of course, provide a definitive case for the application of controls. To do so would require a detailed analysis of costs: not only the costs of potential energy saved but for capital and installation costs and potential maintenance committments. Such costings exist for the examples above but inevitably relative costs for the UK will not necessarily be typical for, for example, Canada, where the availability of hydro power will ensure that the use of electricity is not such a heavy cost penalty as in the UK or parts of the US. The relative costs of different fuels may also substantially affect the implications that savings in lighting have for heating or air conditioning and hence affect the overall efficacy of using lighting controls.

While it would be wrong not to point out these considerations the main aim of this paper has been to indicate the potential impact of lighting controls on energy used for lighting. Here the conclusions can be more positive. There is little doubt from UK experience, some of which has been outlined, and elsewhere [13] that very significant savings can be achieved. Major contributions result from eliminating lighting use when occupants are absent (time switching/scheduling and occupancy linking) and from ensuring that daylight is better utilised (localised switching and daylight linked switching/dimming). The methods by which such contributions can be predicted have been outlined.

In closing, it bears repeating that the provision of convenient local controls for occupants as part of an overall control system can be both energy efficient and, perhaps equally important, has the potential to improve user satisfaction with environmental conditions. Indeed in certain circumstances no further control options may be required. This point is illustrated by an installation of localised lighting monitored under the scheme outlined above [14]. Here the uniform ceiling mounted lighting installation was replaced by a system with limited ceiling lighting for ambient or background illumination and a localised track system which could be tailored to relate to desk positions. The saving in installed load was some 30% but the saving in consumption resulting from discriminating use of the localised luminaires under local manual control, was greater than 80%.

ACKNOWLEDGEMENTS

This paper forms part of the research programme of the Building Research Establishment and is published with the permission of the Director.

REFERENCES

[1] Crisp V H C. The light switch in buildings. Lighting Res. and Tech. 10 (2) 1978.

[2] CIE TC 4.9 Report on lighting economics. Proc. CIE 24th Session, Amsterdam 1983, Vol 2.

[3] Shamus M D. Windheim L S. Reigel P E. and Davy K V. Going beyond the perimeter with daylight. Lighting Design & Application 14 (3) 1984.

[4] Hunt D R G. The use of lighting in relation to daylight and occupancy. Building and Environment 14 1979.

[5] Merrett A J. & Sykes A. The finance and analysis of capital projects. London, Longmans, 1973.

[6] Hunt D R G. Predicting light use - a method based on observed patterns of behaviour. Lighting Res & Tech 12 (1) 1980.

[7] Boyce P R. Observations of the manual switching of lighting. Lighting Res & Tech 12 (4) 1980.

[8] Energy Conservation Demonstration Projects Scheme. What you need to know. 1984. Enquiries Bureau, Energy Technology Support Unit (ETSU), AERE Harwell, Didcot, Oxon OX11 ORA, UK.

[9] Demonstration Project at Civic Offices of Portsmouth City Council. Final Report, 1984. Address as [8].

[10] Demonstration Project at the offices of Bradford Metropolitan Council. Interim Report, 1982. Address as [8].

[11] Demonstration of lighting control applied to light industrial premises (packaging hall). Final report to be published. Preliminary information. Project Profile 138. Address as [8].

[12] Demonstration of lighting control using mains-borne signalling and remot reset in refurbished offices. Final report to be published. Preliminary information. Project Profile 101. Address as [8].

[13] Rubenstein F. & Karayel M. The measured energy savings from two lighting control strategies. Presented at IEEE Industry Applications Society 1982. Annual Meeting. San Francisco. LBL Report 14651.

[14] Demonstration of localised lighting in Civic offices. Final report to be published. Preliminary information. Project Profile 90. Address as [8].

LIGHTING CONTROL:
The Client's Point of View

A.W. Levy

Abstract

This paper suggests there is more than one client in the decision making process that leads to the installation of a lighting control system in a building.

It further describes objectives and influencing factors, within the decision making process, from the point of view of each of these clients.

The impact of third party or innovative financing on the lighting control industry is explored.

CONTRÔLE DE L'ÉCLAIRAGE:
Le point de vue du client

A.W. Levy

Résumé

Le processus de prise de décision qui conduit à l'installation d'un système de contrôle de l'éclairage dans un bâtiment n'engage pas qu'un seul client.

Les objectifs et les facteurs déterminants de la prise de décision sont examinés du point de vue de chacun de ces clients.

L'impact du financement par un tiers ou des nouveaux modes de financement sur l'industrie du contrôle de l'éclairage est également analysé.

Dr. Alan W. Levy
President
Rose Technology Group Limited
74 Willowbank Boulevard
Toronto, Ontario
M5N 1G6

ABOUT THE AUTHOR

Dr. Levy first became involved in lighting in 1975 at the Building Research Establishment in the United Kingdom. There he studied the application of visual performance data to lighting recommendations. He later joined the National Research Council where he established a lighting laboratory and a lighting energy management research program. Among his developments are a portable visibility meter; a solid state, wireless light auditor; an electronic timing switch, and a fibre-optic light switch.

Dr. Levy serves on a number of IES committees, and on the Canadian National Committee of the CIE.

L'AUTEUR

Alan W. Levy a amorcé ses recherches sur l'éclairage en 1975 au Building Research Establishment de Grande-Bretagne, où il s'est consacré à l'étude de l'application des données de performance visuelle aux recommandations sur l'éclairage. Il s'est par la suite joint au Conseil national de recherches où il a mis sur pied un laboratoire et un programme de recherche sur la gestion de l'énergie pour l'éclairage. Il a également mis au point un indicateur de visibilité portatif, un dispositif sans fil à semi-conducteurs permettant d'enregistrer la durée d'utilisation des appareils d'éclairage, une minuterie électronique et un interrupteur à fibre optique.

M. Levy a participé aux travaux de nombreux comités de l'IES et du Comité canadien de la Commission internationale de l'éclairage (CIE).

INTRODUCTION:

This paper attempts to answer the question as to how the client considers or views lighting controls. The question posed is a classical marketing one. A marketing analysis would begin by setting down unambiguous definitions of:

(a) the client or clients

(b) lighting controls

(c) the purpose of the exercise, that is, what are we going to use the results of the analysis for?

Starting with (c), our purpose is to better understand the decision making process that could lead to the installation of a lighting control device or system in a building. A better understanding is sought because a number of experts in this field hold the notion that the benefits of controls are not widely realised or understood. If they were, buildings would be more cost efficient to operate and better satisfy occupant requirements.

We would like a map of the decision making process in order to assist both vendors and users optimise the use of controls in buildings.

Regarding (b), lighting controls will be defined as devices and systems specifically designed to alter, in a controlled manner, the temporal characteristics of all or part of a lighting installation.

Finally (a), describes any person or organizaton who acts either directly of indirectly in the purchase of a lighting control device or system.

There is a common tendency, especially amongst researchers, to concentrate their efforts in new design and construction with less or no interest in the existing building stock. At any point in time new construction activity represents only 2% of the total building stock, so that existing buildings present the greatest opportunity for lighting controls to have any impact. The notion that new techniques and technologies will only be accepted in virgin new buildings ignores the reality that the majority of new design is a repeat of old design that works. As one Dallas developer succinctly expressed it "I don't wish to be first -- I don't want to be second either!" Indeed when a certain lighting control technology becomes a common retrofit it strongly influences new project design.

The market place that is to do with existing buildings will therefore be featured in this paper.

LIGHTING CONTROLS:

A lighting control in this paper controls the amount of time a lighting system operates. This is an arbitrary restriction to meet some objectives of the organisers of this symposium. Not included, therefore, are dimming systems, power reducing devices, and light distribution devices.

The controls about which we wish to describe the client's view are listed below:

- manually operated wall switches
- manually operated timer wall switches
- programmable wall switches
- pull-cord operated switches
- programmable centrally controlled switches
- occupancy sensor switches
- photocell switches

THE CLIENT (S)

If we map the flow of a lighting control product from the factory through to installation in a building, it is apparent that depending who you represent in that progression determines your immediate client. For example in a new building the progression may be:

Representative	Client	Client Considerations
Manufacturer	Distributor	Quality, Cost, Delivery
Distributor	Electrical Consultant	Capability, Availabilty, Price, Reliability
Electrical Consultant	Architect	Price, Aesthetics
Architect	Developer	Price, Necessity
Developer	Prospective Tenant	Functionality

In this example, there are five clients, each with their own interests in lighting controls.

For an existing building, the progression might be:

Representative	Client	Client Considerations
Manufacturer	Distributor	Quality, Cost, Delivery
Distributor	Building Manager	Price, Reliability
Building Manager	Building Owner	Price
Building Owner	Tenant	Operating Costs, Functionality

Here we have some different clients with, in some cases, different interests from those that would exist in a new building design.

It is concluded, therefore, that it is rare that a single client is involved in the process that could lead to a lighting control being installed. Furthermore, the progression is nearly always a sequential one, meaning that each representative client relationship or interaction carries equal importance. If distributors will not carry a product, for whatever reason, it is unlikely that a Tenant or an Owner will be in a position to even consider it's installation. The reasons for not carrying a product are usually economic and not technical, for example, a poor profit margin or inadequate promotion back-up.

The more sophisticated and complex a control, the more service and maintenance will feature in the decision making process for all the clients after the Distributor has fulfilled his function.

In summary, it is suggested that:

- there is more than one client
- each client has a unique set of considerations or views
- considerations or views are different for new and existing buildings

THE STATUS QUO:

If we accept the notion that lighting controls are an under utilised building component, perhaps the question to pose is how can we change attitudes and alter the decisions of the clients identified above. Putting it another way, why don't these clients buy (or sell) more lighting controls.

Perhaps part of the answer lies with the ubiquitous wall switch. It has been around for so long (and so poorly utilised) that it has become the accepted method of lighting control. Anything else will have to prove it's merits against it. In other words, if more than the normal number of switches are to be installed, or a different type of control is to either supplement or replace the wall switch, it must be because the market perceives additional value. This value can be financial or functional. Fluorescent lamps are now common in residential kitchens not because they demonstrate a better life cycle cost versus incandesent lamps but rather their appearance and level of illumination appeal to the consumer.

There is far too little information on the status quo for lighting controls.

How many switches are there in a 'typical' building?

Who is responsible and who is affected by poor utilization?

How important are occupancy patterns and the nature of the activities performed in a space to selecting the appropriate lighting control?

Answers to questions such as these help understand client needs, wants and views; all the way from the initial supplier (the manufacturer) to the user (the tenant). Such information acts as a basis to seek change and act on it. Doing otherwise places heavy reliance on anecdote and opinion.

THE FUTURE:

The future for lighting controls will be dictated more and more by the end user.

The general public have never been more sensitised to the quality of their living and working environment. Building Owners and Tenants pay increasingly more attention to operating costs.

The lighting requirements for the substantial service sector of industrialised economies are changing dramatically with widespread use of visual display units.

In the home the expanded role of the television screen as a two way communications device together with the phenomenal growth in home personal computers will impact residential lighting design.

The simple act of turning a lamp on or off to save money or alter the visual environment may well increase in importance. The technology to perform this function in relation to occupancy, daylight, time of day and space activity exceeds our present capability to understand the client and his interests.

The cost saving feature of lighting controls will figure prominently in the immediate future. A growth industry in North America is Innovative Financing for building retrofit. I.F. is a procedure whereby a third party (an investor) supplies all the capital and cost of labour to perform a building retrofit to lower energy costs. The building Owner pays nothing but agrees to allow the investor to recover his investment from energy cost savings over an agreed period of time. Lighting is a significant energy consumer in many building categories, so that lighting controls will be a much used retrofit tool in the engineered retrofit solutions.

For existing buildings the investment opportunity from installing lighting controls will be a major factor for all clients in the decision making process. Equally important, the decision making process will be consolidated within I.F. companies so that clients and traditional roles will change.

In new building design, lighting controls will feature depending on the state of the art in existing buildings, vacancy rates, tenant demands and improved price-performance ratios for products.

From being a "cinderella" subject just five years ago lighting controls are worth thinking about by researchers, manufacturers, distributors, designers and users.

There are business opportunities to be pursued by comprehending the decision making process amongst the clients.

LIGHTING CONTROL:
The User's Point of View

P.R. Boyce

Abstract

In recent years there has been considerable interest in the application of controls to commercial and industrial lighting installations. The motivation for much of this interest has been to save money and/or energy. However, any such savings may pale into insignificance if the control system adversely affects the motivation of the people working under the lighting installation; so users' reactions to a lighting control system are important. This paper considers the types of control available; manual control, time control, daylight control and occupancy control, and their advantages and disadvantages to users. Field studies of users' reactions to different lighting control systems are reviewed and general conclusions derived. The more important of these conclusions concern the desirability of having a manual over-ride facility; the need to avoid frequent and sudden changes of lighting conditions and the value of ensuring that all users understand the way in which the control system operates and how it may be adjusted.

CONTRÔLE DE L'ÉCLAIRAGE:
Le point de vue de l'utilisateur

P.R. Boyce

Résumé

Le contrôle des installations d'éclairage dans les établissements commerciaux et industriels a suscité au cours des dernières années un vif intérêt, motivé principalement par le désir de réduire les coûts et d'économiser l'énergie. Cependant, ces économies peuvent être négligeables si le système de contrôle diminue la motivation des personnes qui travaillent sous cet éclairage; il est donc important de tenir compte de la réaction des utilisateurs. Cette communication traite des différents types de contrôle, comme le contrôle manuel, les minuteries, le contrôle réglé sur la lumière du jour et le contrôle selon le mode d'occupation ainsi que de leurs avantages et leurs inconvénients pour les utilisateurs. Les résultats d'études portant sur les réactions des utilisateurs aux divers systèmes de contrôle de l'éclairage sont présentés et quelques conclusions générales sont apportées. Ces conclusions examinent principalement l'à-propos des installations manuelles annulant les fonctions des installations automatiques, la nécessité d'éviter les variations fréquentes et soudaines de l'éclairage et l'importance de faire connaître le fonctionnement du système de contrôle à tous les utilisateurs.

Dr. P.R. Boyce
Research Officer
Applied Environment Section
Electricity Council Research Centre
Capenhurst Cheshire
United Kingdom

ABOUT THE AUTHOR

Dr. Boyce did his post-graduate work at Reading University on the subject of human fixation eye movements. After receiving his Ph.D., in 1965, he moved to the Electricity Council Research Centre where he is still employed. He has published numerous papers on people's reactions to lighting conditions and is the author of a book on the subject. He has been active in the affairs of the Illuminating Engineering Society of Great Britain and its successor, the Lighting Division of the Chartered Institution of Building Services; the most important of his activities being as Chairman of the panel which prepared the latest CIBS Code for Interior Lighting. He has also been involved in the affairs of the CIE, having been the British representative on CIE Technical Committee 3.1 (Visual Performance) and author of the technical report on Vision and the VDU Workstation.

L'AUTEUR

M. Boyce a fait des études supérieures à l'université Reading se consacrant particulièrement aux mouvements de fixation de l'oeil humain. En 1965, après avoir obtenu son doctorat, il est entré à l'emploi du Electricity Council Research Centre où il travaille depuis. Il a publié de nombreuses communications ainsi qu'un ouvrage sur la réaction des personnes aux divers modes d'éclairage. Il a participé aux activités de la Illuminating Engineering Society en Grande-Bretagne et à celles de la division de l'éclairage du Chartered Institution of Building Services; il a en outre assuré la présidence du comité chargé de la préparation du dernier code de la CIBS sur l'éclairage intérieur. Il a également contribué aux travaux de la CIE comme représentant de la Grande-Bretagne auprès du comité technique no 3.1 de la CIE (performance visuelle) et comme auteur du rapport technique sur la vision et les terminaux à écrans de visualisation.

INTRODUCTION

Lighting controls provide the means for altering the manner and timing of the operation of an electric lighting installation. All lighting installations have some form of control system. For the vast majority of functional interiors, the control system consists of simple mechanical on/off switches. For a few special applications such as theatres, cinemas and other places of entertainment, more elaborate control systems have been developed. Initially, such systems were complex, cumbersome and expensive but over the last two decades developments in electronic technology have produced a range of control systems with greatly improved capabilities at a cost which makes them available for even the most basic entertainment area. When the rapid escalation of energy costs occurred in the mid-seventies, the possibility of using some of these developments in lighting control systems for functional interiors, such as offices and factories, began to be considered. It should be noted that the motivation behind this interest in lighting control systems for functional interiors was different from that associated with places of entertainment. In places of entertainment, the lighting controls are provided to allow the operator of the space to create lighting conditions appropriate for the activities carried out in that space, which may vary widely from time to time. For functional interiors the motivation has almost always been to save money and/or energy by eliminating the unnecessary use of electric lighting (1,2).

Given this motivation there are two aspects of users' responses to lighting control systems which are important. These are the extent to which users are willing to use a control system and their reactions to the lighting conditions created by the control system. The extent to which people are willing to use a control system is only relevant for systems which have a voluntary element. For such systems, if the users do not wish to or understand how to use the system, the investment in the system will be wasted. Users' reactions to the lighting conditions created by a control system are important for all types of control system. This is because for many commercial enterprises, the cost of energy is only a small percentage of the total costs, which are frequently dominated by salary costs (3). Therefore, if the operation of the control system makes visual tasks more difficult to perform or causes visual discomfort or distraction to the occupants, the potential financial losses arising from poor task performance or low staff morale can rapidly exceed any savings that may be made in energy costs.

This point is reinforced by the fact that in the vast majority of cases, the users of a lighting control system do not gain any financial benefit from any savings that may be made. As far as the users are concerned, the main effect of a new lighting control system is to change the lighting conditions they are used to, with the assurance that energy is being saved. It seems reasonable to assume that whilst most people consider "energy saving" to be a "good thing" in a rather general way, their prime concern will be to ensure that the lighting conditions created by the control system are suitable for their work and do not detract from their visual environment.

The aim of this paper is to review what is known about people's reactions to different types of lighting control system in offices. From this review, some guidelines for the design of lighting control systems will be derived. The purpose of the guidelines is to ensure that future lighting control systems are likely to be used and do not create adverse user reactions. This review is restricted to offices because this is the only area of application for which much published work exists.

CONTROL OPTIONS

Lighting control systems can take many different forms depending on the type of lighting to be controlled, the costs and benefits of different types of control and the pattern of use of the area to be controlled. However, any control system can be conveniently described in terms of three characteristics: the stimulus that is used to trigger the control action, the type of action that results and the area over which that action occurs. The options available under each of these headings are shown in Figure 1.

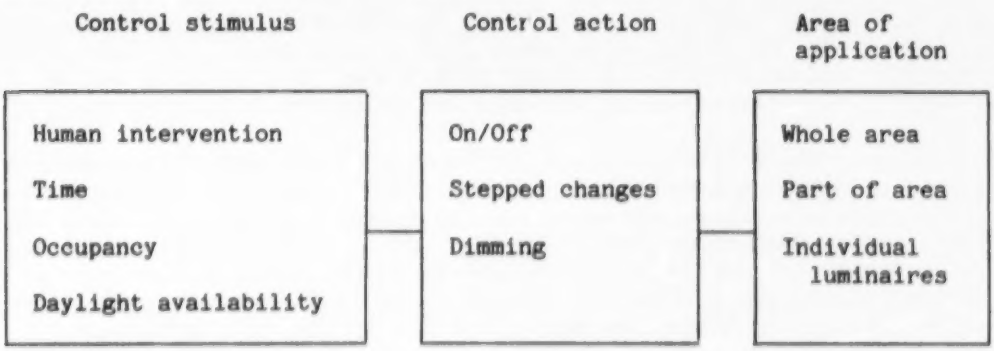


Figure 1 The options for lighting control systems

There are four different stimuli commonly used to initiate a control action. They are human intervention, the passage of time, a change in the state of occupancy of the lit space and a change in the availability of daylight. Human intervention is involved whenever the operation of the control system requires human initiative. It is by far the most common form of control system, occurring as mechanical switches of various forms in many offices. Time as a stimulus to a control system is less common but it is very simple to implement, requiring only a time switch set to appropriate values. The level of occupancy can also be used as a control stimulus. Sensors based on infrared radiation, ultrasonic sound and audible sound can be used to detect the presence or absence of people in a lit space and hence to modify the lighting. Daylight, as a stimulus to control, is also easy to implement. It requires one or more sensors which detect the amount of daylight available, either outside or inside the building, and the appropriate circuitry to adjust the electric lighting installation.

Given that one of these stimuli has initiated a control action, the luminaires which constitute the lighting installation can be made to

respond in several different ways. The most common response is a simple on/off action in which the luminaire is either producing full light output or nothing. In multi-lamp luminaires, switching of individual lamps can be used to give a series of steps of light output from a luminaire. Dimming is also a possibility. Dimming may be continuously variable or between a series of preset levels. In either case dimming is much less conspicuous than switching.

The third characteristic of the control system is the area over which the control action occurs. This may be the whole area covered by the lighting installation, which can vary from an individual office to a large open plan area, or it may be only a part of the area lit by the lighting installation which can range from a significant proportion of the lit space to the area lit by a single luminaire.

These three characteristics of a control system are commonly combined in certain ways. Control systems using daylight availability as a stimulus are usually connected to first affect that part of the lighting installation near the windows, unless the rooflights giving a uniform distribution of daylight are involved. Time switching is often applied to the whole of a large lighting installation, although a few luminaires may be left operating for security reasons. Simple mechanical on/off switching requires human intervention so it can have various degrees of flexibility from the rigid, where a large installation is controlled by one switch, to the very flexible, where each luminaire has its own switch. The more sophisticated control systems are designed to respond to more than one of the stimuli. Nearly all control systems have a manual component which allows human intervention. Many also have time switches and in some cases this is combined with a sensitivity to daylight or occupancy.

The important point to note about the control options is that there is no such thing as a standard lighting control system. The control system designed for a lighting installation will depend on the possibilities presented by the situation; is daylight available in reasonable quantities, is the pattern of occupation stable, is the interior a large open space or a series of small rooms, can the lighting installation be dimmed or can it only be switched, what are the requirements for safety and security, and so on. Given this number of factors it should not be too surprising that lighting control systems can vary from the very simple to the complex, sometimes forming a part of a complete building energy management system.

USER REACTIONS TO LIGHTING CONTROLS

Although there have been several studies of the financial/energy savings associated with the use of lighting control systems in offices (1,4), there have been few systematic investigations of people's reactions to the lighting conditions created. Those that have been done have all been associated with field trials of a specific lighting installation. This is no bad thing. Field studies have the great advantage of obtaining the reactions of people who have had prolonged experience of the control system operating whilst they are undertaking their normal working activities.

Manual switching

The most primitive type of lighting control system is one which automatically switches the lighting on at the beginning of the working day and off at the end, without any provision for human intervention (4). Such a system frequently leads to the lighting being energised when spaces are not occupied and hence to energy being wasted. One way to avoid this problem is to introduce some manual switching into each office. The problem with this proposal is whether such switching will be used. Hunt (5,6) carried out observations, using time lapse photography, of the way in which people used manual switches in three small multi-person offices. All three offices were lit by ceiling-mounted fluorescent luminaires switched from panels near the door. In two offices, (A and B) the switching was arranged in such a way that each switch controlled a row of luminaires running parallel to the window wall. In the remaining office (C) the switching was not arranged in a regular manner, largely because this office had been created by joining together two smaller rooms, each with its own lighting and switching system. In all three offices, daylight made a significant contribution to the lighting. All three offices were continuously occupied during the working day. The observations were made for a 6 month period covering half the daylight availability cycle (January-June or July-December). From his observations, Hunt showed that the use of the switches in all three offices was governed by the level of daylight in the space when the office was first occupied. The tendency was for the lighting to be switched on at the beginning and off at the end of the working day (Fig. 2). The probability of lighting being switched on at the beginning of the working day was most closely related to the minimum illuminance on the working plane that occurred in the room at that time. Once the office was occupied, the lighting was rarely switched on or off. At the end of the working day the lighting was usually switched off by the last person to leave.

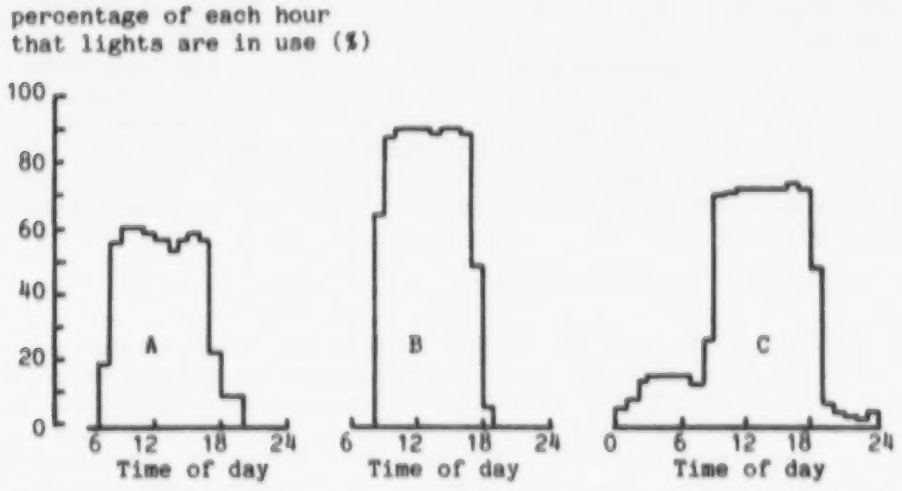


Figure 2 Six month average percentage of each hour that lights are in use plotted against time of day for three multi-person offices equipped with manual switching. Some night shift working took place in office C (after 5).

It is important to note that these results were obtained in continuously occupied offices. Hunt (5) also studied the use of similar manual switching in school classrooms which were intermittently occupied. Here, the switching pattern followed the pattern of occupation, i.e. the lighting tended to be switched on at the beginning of each period of occupation, if there was judged to be insufficient daylight, and off at the end of each period of occupation.

The manual control systems used in Hunt's studies (5,6) are typical of those used in many offices. They consist of a few switches, each controlling a number of luminaires, the switches being positioned close to the door of the room. In an attempt to encourage people to use manual switching some designers have expanded the number of manual switches so that each switch operates only a few luminaires, thereby giving greater opportunity to the users to manipulate the lighting conditions.

Boyce (7) carried out observations of people's use of one such installation over a two week period, one week in winter, the other in summer. The location was two large but narrow open plan offices, each with windows on the two long sides, lit by a regular array of recessed fluorescent luminaires. The normal switching was arranged at two levels. The first level was two switch panels located on columns along the main circulation route through the office, each switch controlling half a row of luminaires, each row running parallel to the windows. The second level was at the luminaire, each luminaire being individually switched by a pull-cord switch. The wiring of the switches was in series so for a luminaire to be lit both the column-mounted and the pull-cord switch had to be on. Figure 3 shows the number of luminaires on at half-hourly intervals during one working day in the two offices in summer and in winter. The first point to note is that the number of luminaires on does change during the period of occupation, although most of the change occurs around lunchtime when the levels of occupancy were much reduced. Indeed much of the switching was done by people as they were leaving or entering the office. The second point is that there are clear differences between the two offices in the two seasons. The effect of season is not unexpected in that it relates to the availability of daylight at the time the office is occupied. Much more daylight is available in summer at the start of the working day than in winter. What is not expected is the difference between the two offices in both summer and winter, since both have the same lighting installation and the same control system and the occupants do similar work. Detailed examination of the data collected suggested that the difference arises partly from the different patterns of occupancy of the two offices, the internal audit office having many more staff coming and going than did the accountancy office, and partly from the fact that manual switching is voluntary and relies on individual initiative. The individual initiative arose because some of the users expressed a marked dislike of fluorescent lighting, as such, and so turned off the luminaires in the immediate area of their desks, using the pull-cord switches, as soon as sufficient daylight was available. Other initiatives came from some of the supervisors in the Internal Audit office, who turned off the lighting when they thought sufficient daylight was available. The supervisors tended to use the column mounted switches for this action.

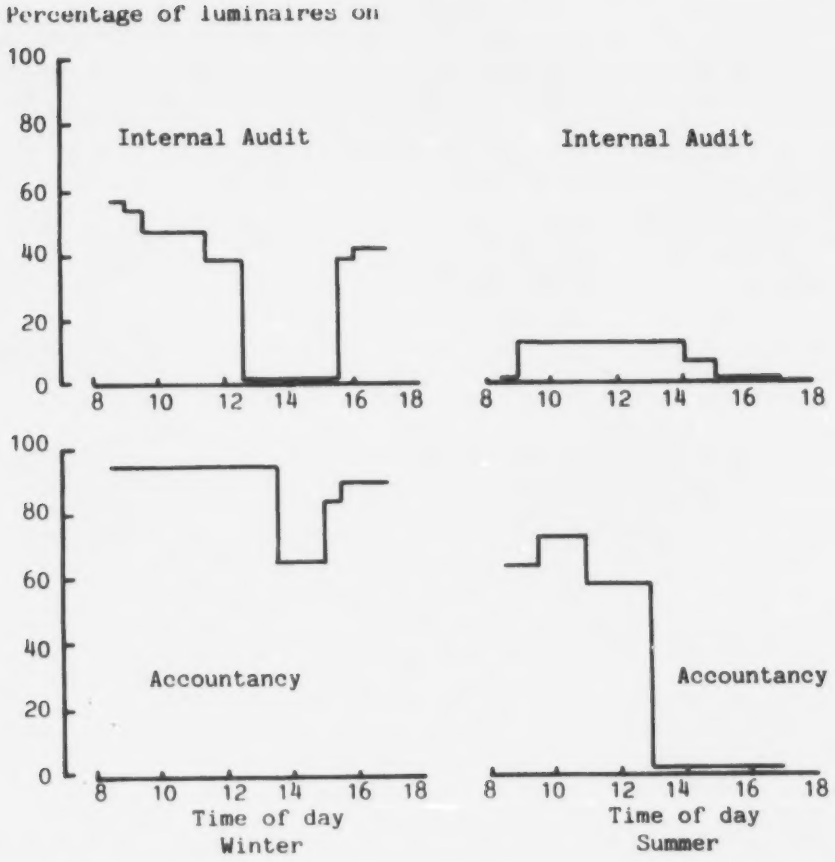


Figure 3 Percentages of luminaires on in two open plan offices equipped with manual switching plotted against time of day for one day in winter (5th December) and another in summer (26th June) (after 7).

In order to encourage such initiatives the study indicated that it is desirable to have the organisation of the switches matched to the functional organisation of the office and to the availability of daylight. Observation showed that the supervisors only switched the lighting which affected the area they were responsible for. When one switch changed the lighting over several working groups it was unlikely to be used. It is also important to note that the switching should be divided to match the gradation of daylight. If this is not done then it is unlikely that any switching will occur until there is sufficient daylight to satisfy the requirements of the people furthest from the windows.

A comparison of the studies of Hunt (5) and Boyce (7) shows that increasing the flexibility of manual switching will lead to a saving in the energy used for lighting. Certainly more switching of lighting took place during the period of occupation for the office with the greater degree of individual control (7). This point is reinforced by study of Alexander et al. (8) comparing a uniform lighting installation

and a localised lighting installation over a six month period, April-October, in an open plan office with extensive solar control glazing. The uniform lighting installation was switched in rows of luminaires running parallel to the windows from a switching panel located in a meter room near the entrance to the office. The localised lighting installation had two components: background lighting provided by a regular array of ceiling mounted luminaires and localised task lighting provided by fluorescent luminaires suspended over work stations. The background lighting was switched in rows running parallel to the windows from panels located at two positions in the office. Each luminaire of the localised task lighting was switched individually at the luminaire. This individual switching gave the occupants considerable control of the lighting of their working areas. The recordings of switching showed that the office lit by uniform lighting had a similar switching pattern to that found by Hunt (5); the installation tending to be switched on at the beginning of the day and off after the office cleaners had finished their work. The switching pattern for the localised lighting installation was different. Whilst the background lighting tended to be switched on at the beginning of the day and off at the end of the day, the localised task lighting was switched frequently throughout the day (Fig. 4). (The high percentage of switch ons for the background lighting at 1800 hrs is due to the office cleaners.)

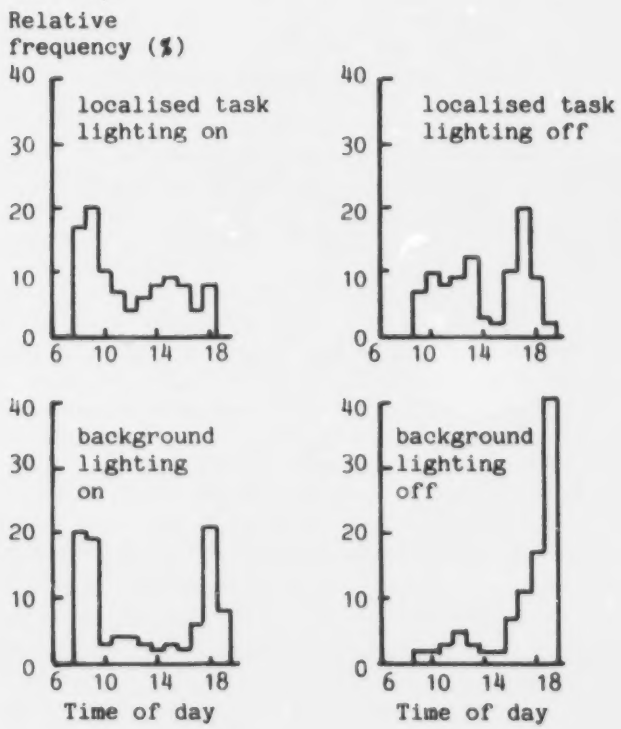


Figure 4 The relative frequency with which the localised task lighting and the background lighting were switched at different times of the day (after 8).

In their experiment, Alexander et al. (8) also obtained the users' reactions to the two lighting systems. The occupants gave ratings of their satisfaction with the lighting conditions provided, in general and as regards the amount and uniformity of lighting on their desks. Overall, and as regards the lighting of their desks, the occupants considered both the uniform lighting and the localised lighting installation to be satisfactory. However, the energy consumed by the localised lighting installation over the summer period studied was very much less than that for the uniform lighting installation.

Occupancy switching

A rather different type of control system is one which concentrates on the elimination of waste by ensuring that lighting is turned off at times when the lit space is unoccupied. This can be achieved by simple time switches if the pattern of use of the installation is consistent and is predictable. It can also be achieved by using sensors which can detect the presence of people in the office. Turner (4) reported a study of the use of infrared occupancy sensors in two office blocks. The sensors detected movement and radiation from a body so that the lighting of the room was switched on whenever the room was occupied, and switched off soon after the room was vacated. In both offices, some 30-40 rooms had an occupancy detector installed. Most of the rooms were small offices containing one or two individuals. The local manual switching that was available in one building was disconnected so no manual switching was possible. Measurements taken over a three month period showed that the occupancy control saved energy and hence money. Interviews with the occupants were used to determine their reactions to the control system. Where the control system was working as designed, there were no adverse reactions. Indeed, there was general approval of the concept of energy saving through controlled lighting. However, in four offices, the control system was removed at the occupant's request for the following reasons. In one case the control system occasionally turned the lights off when the space was occupied. In another the occupant of the office wished to turn off the electric lighting to use daylight. The occupancy control system did not have a manual override so this was not possible. In the final case, two adjacent offices were separated by a partial partition so the lighting of one office was dependent on light from the adjacent office. Therefore, if the occupancy sensor in one office switched off the lighting when the other office was occupied, the lighting of the other office was diminished. None of these reasons can be considered as condemning occupancy switching but they do illustrate the need for thought when applying a completely automatic system to diverse circumstances.

Daylight control

Control systems which automatically switch the luminaires located close to a window as daylight varies have been available for many years. However, knowledge of people's reactions to these systems is anecdotal. It is widely believed that such control systems can be satisfactory, but are likely to produce adverse reactions from users if the switching is frequent.

This belief is supported by a study of a more complex system (9). The office studied was open plan and occupied by engineers and specialists concerned with power station design. The lighting was provided by a regular array of surface-mounted fluorescent luminaires. The control system provided for the two rows of luminaires closest to the window to be dimmed to preset levels of 70% and 40% of light output and then switched to zero light output, depending on the amount of daylight available. The next two rows of luminaires could be dimmed to 70% and 40% of light output. The central part of the installation could not be dimmed at all. The dimming from 100% to 70% and from 70% to 40% of light output took 20 seconds, but the change from 40% to zero light output was instantaneous. The increase in lighting from zero light output always involved an instantaneous return to 100% light output before dimming could occur to 70% or 40% of light output. Manual switches were located in the office, which allowed the occupants to switch groups of luminaires on or off but this switching could itself be overridden by the automatic control system after a maximum delay of half an hour.

This control system was found to produce energy savings (10) but there was a considerable level of dissatisfaction with its operation (9). Some 70% of a sample of users considered themselves as being moderately, slightly or very dissatisfied. The causes of dissatisfaction volunteered by the users were the on/off operation of the perimeter lighting (73%), the tendency of the lighting to flicker (29%) and the humming noise produced by the lighting on some occasions (16%). The complaints about the lighting flickering and humming can be put down to the teething troubles with the control system but the complaints about the on/off perimeter lighting cannot. This part of the system was operating as intended. Further questioning revealed that many users found the perimeter switching to be distracting, a complaint which was enhanced by the frequency with which the system allowed such switching to occur. In one exceptional hour, the system switched the perimeter lighting seventeen times (10). Another basis of complaint was the changed nature of the lighting produced when switching occurred. Some of the users found the change in intensity and direction of shadows created by hands and drawing instruments when switching from predominantly overhead electric lighting to predominantly sideways daylighting, distracting.

It is interesting to note that the complaints obtained are about the instantaneous switching of the perimeter lighting. The dimming element of these controls apparently produced few complaints. Crisp (11) mentions a similar finding in a study of teachers' reactions to an automatic control system for classrooms. In this case the rows of luminaires closest to the window had automatic on/off controls whilst the next rows in had continuously variable dimming related to the available daylight. The limited data collected suggested that there were more "negative" responses to the on/off controls than to the dimming controls.

Combined systems

In recent years, lighting control systems have been designed which incorporate a number of different control stimuli. An example of such

a system is that installed in the Portsmouth City Council offices. This building is a modern, six floor, office block with extensive open plan accommodation, housing about 1000 occupants. The lighting installation consists of bare fluorescent lamps mounted above a metal louvre suspended ceiling. There is extensive daylighting from large windows on two sides of each office. As far as the occupants are concerned, the lighting control system installed has three components: (a) time switching which switches the lighting on at the beginning of the working day and off at the end of the conventional working day, with "off" signals occurring at half hourly intervals subsequently; (b) local manual switching from panels which allow the occupants to switch on small groups of luminaires and (c) automatic switching of the luminaires closest to the windows according to the amount of daylight available. Therefore the control system responds to human initiative, time and daylight stimuli.

A careful study has been made of the occupants' reactions to the system (12). The approach adopted was that of group discussions with a sample of people from the office as well as the administration of questionnaires to the discussants. In all, seven groups, each of about eight people, took part in the discussions, care having been taken to obtain people representative of those employed in the building. The topic of discussion which is of interest here is the occupants' satisfaction or otherwise with the lighting control system and the reasons for their satisfaction or dissatisfaction. In fact, the responses obtained suggested that the occupants were evenly divided between those who were satisfied and those who were not. Figure 5 shows the distribution of satisfaction ratings. It can be seen that there is a double peak, one peak over the "moderately satisfied" rating, the other over

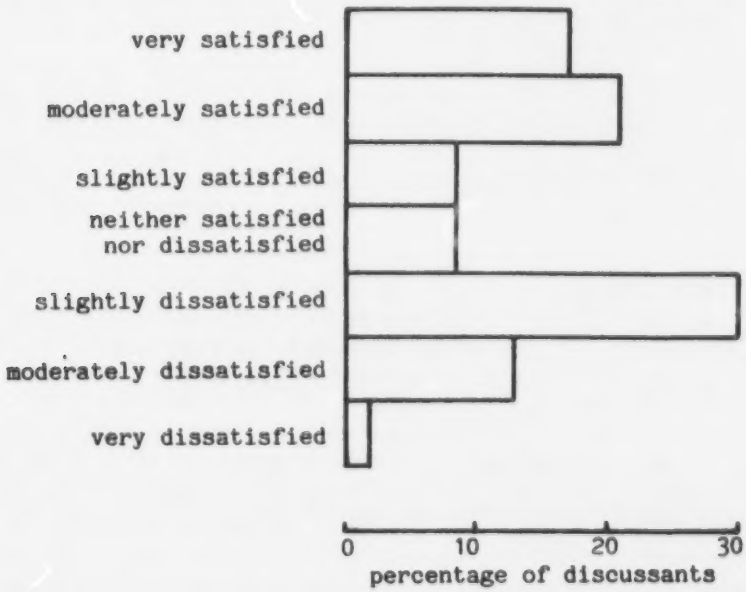


Figure 5 Percentage of discussants expressing different degrees of satisfaction/indifference/dissatisfaction with the lighting control system (after 12).

the "slightly dissatisfied" rating. During the discussion, participants were asked to state any complaints they had about the control system and in the questionnaire they were asked to give the main reason for these complaints. Table 1 shows the percentage distribution of the complaints by the ratings of satisfaction/indifference/dissatisfaction.

Nature of complaint	Satisfaction rating		
	Satisfied	Neither satisfied nor dissatisfied	Dissatisfied
Perimeter lighting	9%	2%	33%
Time switching	9%	0%	4%
Manual override switching	4%	0%	9%
No complaints	24%	6%	0%

Table 1 Percentage of discussants complaining about different features of the lighting control system classified according to their rated satisfaction (after 12)

From Table 1 it can be seen that the major problem experienced is with the perimeter lighting controlled by daylight, although there is some dissatisfaction with the operation of the time clock and the local reset switches.

The complaints about the perimeter lighting had two causes. The first was simply that the automatic switching off of the luminaires near the window occurred when the staff in that area felt the daylight available was insufficient. When this occurred, the staff had to stop work and go to the local switching panel to turn the lighting on again, an action which they considered both distracting and time consuming. The second cause of complaint was more general. It was simply distraction caused by the lighting in part of the room switching on and off for no apparent reason.

The complaints about the time clock were only made by a few people but that is almost certainly because only a few people were affected. The cause of the complaint was that when working late the automatic control system reduced the lighting to a much lower level every half hour. This meant that every half hour the occupants had to leave their work and override the automatic control by the manual switching. This again, was considered disruptive and time consuming.

The complaints about the local switching panel arose from the fact that it did not allow the occupants to switch the lights off. It only allowed them to switch the lights on. Only being able to switch the lights on was regarded as a limitation on the individual's control of the environment and contradictory to the energy saving objectives of the control system.

It was interesting to note that this study also produced some evidence to suggest that different occupations in the office view the lighting control system differently. The sample of people taking part in the discussions were divided into three types of jobs: administrative, clerical and drafting. The division between satisfied and dissatisfied with the control system was similar for both administrative and clerical workers at about 50/50 but for drafting work, some 80% were dissatisfied. The people engaged in drafting work were using detailed plans, maps and diagrams and had task lighting attached to the drawing boards. The single reason given for their expressed dissatisfaction was the operation of the perimeter lighting, the sudden change in lighting being considered distracting and disruptive.

SOME GUIDELINES

It should be evident from the above review that there are only a few studies in which user reactions to lighting controls have been carefully examined. Even where such studies have been made, it is important to note that the results obtained are specific to the system studied and to its limitations. For example, the fact that the switching of perimeter lighting according to the amount of daylight available was the source of some dissatisfaction does not mean that all such control actions will cause dissatisfaction. It may well be that by changing the illuminance at which switching occurred or by using dimming rather than on/off switching, dissatisfaction could be much reduced.

In these circumstances it is not possible to reach any definitive conclusions. Rather, the best that can be done is to devise some guidelines to the important aspects of different types of control system as regards their potential for energy saving and users' reactions to them.

Manual switching

The best way to describe the effectiveness of manual switching for energy saving is as having great expectations but uncertain use. The uncertain use arises because manual switching is essentially a matter of individual initiative. Individual initiative is readily applied to a space over which the individual has control but is less likely to be used in areas for which no individual is responsible or where operating a switch will affect the lighting of other people. Essentially the difference is between "private" and "public" lighting. The more "private" the lighting is considered to be, the more likely is the use of the switch. "Private" lighting can be created by ensuring that each switch operates only a few luminaires and that the switch is located close to the work area. Unfortunately, the more "private" the lighting is, the less the energy saved for each switch operation.

If "private" lighting is not feasible and "public" lighting is to be switched, the probability of it being used will be increased if the switch panel is located in an easily accessible place and laid out in such a way that the relationship between the switches and the luminaires is clear.

As for users' reactions to manual switching, there can be little doubt that users value having some control over their environment. This is especially important when other automatic lighting control actions are in operation. Without manual switching, if the automatic control fails or is inappropriately set, then the occupants have little choice but to endure the prevailing conditions which may well lead to dissatisfaction and disruption of work. For this reason, it is always wise to incorporate an element of manual control in a lighting control system.

Time control

Time control consists of two types. The first type is that used to eliminate the use of a lighting installation when the lit space is not occupied. The second type is that used to turn off lighting when the space is occupied but there is likely to be sufficient daylight available.

Switching at set times after the end of the working day has been shown to be effective in saving energy in buildings where waste is obvious (10). User reaction to this type of control depends on the extent to which the predictions of the pattern of use are fulfilled. If the predictions are correct then the user reaction is non-existent because there is no one there when the control action occurs. The problem occurs when the predictions are wrong. In this situation a degree of manual control can provide the necessary flexibility.

One particular form of time control which deserves attention is the automatic switch-on at the beginning of the working day. This system has been used in a number of installations but, if manual switching is included in the design, an automatic switch-on seems unnecessary. People can be relied upon to switch the lighting on should they need it.

Switching at set times when the office is occupied is another type of time control. The idea behind this is that the switching is done at a time when there is likely to be sufficient daylight available for lighting the room. If there is not then the occupants can switch the electric lighting on manually. Users' reactions to this method of control are likely to be governed by the frequency with which it occurs and the amount of daylight available at the time. Experience suggests that once at lunchtime and even twice, once mid-morning and once at lunchtime, is unlikely to cause any problem provided the area is well daylit, but more frequent switching can be expected to cause considerable dissatisfaction amongst users. This type of time control is undoubtedly effective in saving energy but requires using with discretion.

Occupancy control

Occupancy control aims to turn off the lighting in offices or parts of offices which are unoccupied. Again there is evidence that occupancy control of lighting can save energy without inducing adverse user reaction (4). Indeed, since the essence of occupancy control is that no one is present, it is difficult to see how there could be any user reaction unless the control system fails.

It is worth noting that occupancy control could probably be applied to separate parts of a large open plan office. It might be thought that the illuminance uniformity criteria conventionally applied to uniform office lighting would prohibit such a use and indeed they do. However observations of people's pattern of voluntary switching in a partially occupied large office suggest that a uniform illuminance over the whole of a partially occupied office is not essential (7).

Daylight control

The aim of daylight control is to adjust the electric lighting according to the distribution of daylight available. This adjustment can be achieved by switching or dimming luminaires. The evidence available shows that in appropriate circumstances daylight control can save energy (10). However, there is also evidence that switching in response to daylight variations can cause considerable dissatisfaction, either because the system is inappropriately set as regards the illuminance provided on the work or simply because of the distraction caused by frequent changes in response to frequent daylight variations. If dimming were used, with its gradual variation in illuminance, it seems likely that distraction as a cause of dissatisfaction would be reduced. Of all the control options, daylight control, particularly switching, seems to carry the highest risk of creating user dissatisfaction. For this reason, careful consideration should be given to the value of daylight control before including it in any automatic control system. Indeed, in many situations it might well be better to rely on timed switch offs during mid-morning or lunchtime to collect most of the energy savings available when there is plentiful daylight in the office.

OTHER CONSIDERATIONS

All the above guidelines have been concerned with the selection of control options. It should be noted that selecting the control options and designing and commissioning the system are only parts of the process of installing a lighting control system. Another part is ensuring that the occupants understand the operation of the control system: what it can do, what it cannot do, and how it can be adjusted (9,12). If this is done the users of the lighting can understand what is happening and may be able to adjust the system to meet their requirements. If it is not, then the control system may well be considered an imposition and dissatisfaction result.

THE FUTURE

The above description of users' reactions to lighting control systems has reflected present-day concerns in that it has been devoted to the use of lighting controls to save energy without producing adverse user reactions. However, the more positive role of lighting controls should not be forgotten. Lighting controls can provide the means whereby the occupants of an interior can adjust the lighting to their own requirements. At present it is rare for lighting controls to be used in this way in functional interiors, except in individual executive offices. This is due in part to the cost of the equipment required to

produce varying light outputs, from different light sources. If, as seems likely, electronic control gear becomes more widely available in the near future, then many conventional and comprehensive lighting installations will be capable of being adjusted by their occupants. If this happens, lighting controls may provide the format for a new approach to lighting design.

REFERENCES

1. Crisp, V.H.C. Lighting controls to save energy. International Lighting Review, Vol. 34, No. 1, 1983, p. 16-21.

2. McGowan, T.K. The economic analysis of lighting systems with control. Commission Internationale de l'Eclairage, 20th Session, Amsterdam, Vol. 1, 1983, p. D701/1-4.

3. Daryanani, S. Design considerations for the daylighting of new commercial buildings. General Proceedings 1983 International Daylighting Conference, American Institute of Architects, New York, 1983, p. 189-190.

4. Turner, O. Occupancy controlled lighting: energy savings demonstration and analysis. Tishman Research Corporation, National Technical Information Service, US Department of Commerce, PB 83-227546, 1982.

5. Hunt, D.R.G. The use of artificial lighting in relation to daylight levels and occupancy. Building and Environment, Vol. 14, No. 1, 1979, p. 21-33.

6. Hunt, D.R.G. and Cockram, A.H. Field studies of the use of artificial lighting in offices. Building Research Establishment Current Paper 47/78, 1978.

7. Boyce, P.R. Observations of the manual switching of lighting. Lighting Research and Technology, Vol. 12, No. 4, 1980, p. 195-205.

8. Alexander, D.K., Crisp, V.H.C., McKennan, G.T. and Parry, C.M. Localised lighting - a low energy alternative to uniform lighting in offices. CIBS National Lighting Conference, Canterbury, 1982, p. 112-125.

9. Gaskell, G. and Pike, R. The behavioural monitoring of the GEC-Osram advanced lighting control system. To be published by the Energy Technology Support Unit, Harwell, UK, 1984.

10. Carver, M. The monitoring of energy savings associated with automatic lighting control. CIBS National Lighting Conference, Cambridge, 1984, p. 112-127.

11. Crisp, V.H.C. Photo-electric control of lighting - case studies. in "Experience of energy conservation in buildings" edited by A.F.C. Sherratt, Construction Press, London, 1981.

12. Energy Technology Support Unit, The evaluation and demonstration of the ECS 500 lighting control system, ETSU, Harwell, UK, 1984.

LIGHTING CONTROL:
Application and Integration

Terry K. McGowan

Abstract

As the application of lighting controls has expanded from simple on/off and architectural or theatrical functions to include more complicated energy management roles, a number of application problems have arisen. These generally involve the operation of discharge lighting systems with proportional control equipment, ballast and control compatability, and potential cost and energy savings.

This paper discusses these problems and lists a set of simple guidelines describing what controls must do to keep lighting efficacy high and to avoid performance problems such as lamp flickering, short life, and poor lumen maintenance.

Also discussed is some application experience which has begun to indicate which control strategies are most helpful and what types of controls might be developed to better match the needs of the lighting user and the characteristics of the lighting equipment.

CONTRÔLE DE L'ÉCLAIRAGE:
Application et mise en oeuvre

Terry K. McGowan

Résumé

À mesure que la mise en oeuvre du contrôle de l'éclairage a débordé du cadre des simples dispositifs allumage/extinction, et des fonctions théâtrales et architecturales pour inclure des fonctions plus complexes liées à la gestion de l'énergie, un grand nombre de problèmes ont surgi. En général, ces problèmes se rapportent aux systèmes d'éclairage à décharge avec équipement de contrôle proportionnel, à la compatibilité entre le ballast et le contrôle, et à la réduction des coûts et de la consommation d'énergie.

Cette communication traite de ces divers problèmes et propose une série de directives simples décrivant les caractéristiques que doit posséder un système de contrôle afin de maintenir une haute efficacité de l'éclairage et éviter les problèmes de performance comme le papillotement des lampes, une courte durée de vie et une faible intensité du flux lumineux.

Quelques résultats d'expériences sont présentés; ces expériences fournissent des indications préliminaires sur l'efficacité des méthodes de contrôle et sur les divers systèmes qui pourraient être mis au point afin de répondre davantage aux besoins des utilisateurs et aux particularités de l'équipement d'éclairage.

Terry K. McGowan
General Electric Company
Lighting Business Group
Nela Park #4162
Cleveland, Ohio 44112

ABOUT THE AUTHOR

Mr. McGowan is a senior specialist with General Electric's Lighting Technology Group at Nela Park in Cleveland. His present assignments include application engineering for offices, schools, and hospitals, system development and evaluation for lighting control systems, light source technology assessment and lighting education.

An author of numerous articles and technical papers, Mr. McGowan is a member of the IEEE, the U.S. National Committee of the International Commission on Illumination, a Fellow of the Illuminating Engineering Society and Chairman of the IES Lighting Economics Committee. He is a graduate of Cleveland's Case-Western Reserve University with a degree in Electrical Engineering.

L'AUTEUR

Terry K. McGowan est ingénieur-éclairagiste supérieur pour le Lighting Technology Group de la General Electric Company à Cleveland. Il se consacre actuellement à l'application des techniques d'éclairage dans les bureaux, les écoles et les hôpitaux, la mise au point et l'évaluation des systèmes de contrôle de l'éclairage, l'évaluation de la technologie des sources de lumière et à l'éducation dans le domaine de l'éclairage.

Auteur de nombreux articles et documents techniques, Terry McGowan est membre de l'IEEE, du U.S. National Committee de la Commission internationale de l'éclairage, Fellow de l'IES et président du Lighting Economics Committee de l'IES. Il est diplomé en génie électrique de la Case-Western Reserve University de Cleveland.

INTRODUCTION

Lighting controls have traditionally been considered in the context of architectural applications where needs such as dimming, decorative lighting effects, or perhaps flexibility are important. Now the situation is different and attention is being focused on the use of lighting controls for energy management. This is a time when new control products are appearing in the market place, when questions are being raised as to how to apply these controls, and when it is clear that a good match must be made between the lighting requirements and the lighting equipment in order to control lighting energy efficiently without compromising lighting quality and quantity.

OBJECTIVE: AN OPTIMUM MATCH BETWEEN THE LIGHTING CONTROL AND THE LIGHTING USER

This report focuses on two specific considerations involved in the application and integration of lighting controls. The first is the problem of properly coupling the control system to the lighting system. The second is the potential for using lighting controls not only to reduce lighting energy, but also to improve lighting quality.

FACTOR I: THE LINK BETWEEN THE LIGHTING CONTROL AND THE LIGHTING CIRCUITRY

Controls which simply turn the lighting circuit on and off do not cause any particular system performance problems as long as frequent on/off cycles are avoided if discharge lamps are involved. In the case of high intensity discharge (HID) systems there are also the practical considerations of allowing time for the lamp to warm up or allowing it to cool down for restart.

Frequent switching shortens the life of both fluorescent and HID lamps and the effect can be substantial depending upon the lamp type involved. There has been some confusion about this point due to some published material which has mixed up the ideas of lamp life reduction, energy use, and economics.

Switching discharge lighting systems does not produce an "energy surge". Lamps go from an off state to full output under the control of their ballasts whose circuitry limits the power drawn from the power supply. Frequent switching, however, may be more costly from the financial standpoint than permitting a discharge lamp to burn because of the life reduction. Should lamps be turned off to save energy or should they be left on to minimize costs, is usually the question asked when lighting is not needed for brief periods such as during breaks in factories and offices.

The "break-even" point can be determined by using a relationship which equates the cost/time with the lamps burning to the cost/time with the lamps turned off and then on again over a cycle period. /1/

As a general rule, the break-even time decreases as electric energy rates increase. Current calculations for fluorescent systems indicate the break-even point is less than 5 minutes assuming 8-10 cents/kWh and typical figures for lamp and replacement labor costs. For HID systems the break-even point is 20-30 minutes because of the higher unit costs for HID lamps compared to fluorescent lamps.

The reason that discharge lamp life is reduced by switching is that life is primarily determined by the condition of the cathodes in the lamp arc tube. During manufacture, the cathodes are coated with a material called emission mix so that the lamp starts easily and the arc, once established, remains stable. As the lamp burns, some of the emission mix sputters off the cathodes and may show up as a dark deposit on the inside of the arc tube surface. This is the blackening which is sometimes noticed on the ends of fluorescent lamps. During starting relatively more of the emission material sputters off than if the lamp had burned for a certain period. When the emission mix is gone, the lamp starting and operating voltages rise to beyond what the ballast can supply and the lamp either does not start, begins to flicker or otherwise operates in an unstable manner indicating the end of life.

From a practical standpoint lighting controls which might turn discharge systems on for very brief periods should perhaps be equipped with delay circuits set to the break-even point;although as energy rates continue to increase, fluorescent system break-even points, now already quite brief, will continue to shorten. Also, improvements in lamp cathodes are making starting less destructive for lamps such as the common F40 rapid start so that the best way to operate fluorescent systems may well be to simply turn them on and off as needed. Lighting controls with a delay feature built in are commercially available. Certain types of infrared sensor switches, for example, are equipped with an adjustable minimum on period setting.

General service incandescent lamps are not sensitive to on/off cycles although this is absolutely true only for lamps early in their life. As the lamp burns and the filament develops "hot spots" along its length, on/off cycling seems to encourage somewhat higher filament evaporation at those hot spots. When the lamp is ready to fail, the failure will usually occur at the hot spot upon turn on. Nevertheless, reported experiments do not indicate more than a few hours difference in life between lamps which are burned continuously and those which are switched frequently. /2/

Lamp manufacturers determine lamp life ratings using lamps burned on test racks which are cycled on and off so published ratings have any effects due to switching built in.

PROPORTIONAL CONTROLS

The use of proportional controls adds some complications to both the control circuitry and the way lighting systems operate. Incandescent systems are quite forgiving, fluorescent systems less so, and HID systems least of all. As power to a light source is reduced, the first performance characteristic to suffer is usually lamp efficacy (lumens/watt). This is because for general lighting lamps efficacy is the prime design factor and system trade offs have been made with that in mind. Consider, for instance, a fluorescent lamp which is designed to operate at 40 watts. The ballast is sized to provide the proper voltage and current, but no more than necessary for reliable operation since there are magnetic, resistive, and capacitor losses which must be minimized. The lamp cathodes are built to carry about 430 mA continuously without overheating and a set of cathode coils at the ends of the lamp is set to a constant temperature via a separate circuit to ensure that the lamp will start without sputtering. If the lamp is now operated at a lower power level, light output (lumens) will drop, watts in the arc will drop, but the fixed power losses in the cathode and ballast circuits will remain relatively high. All electric light sources have some fixed system losses.

The basic mechanism utilized in the light source to transform electricity into light may also become less efficient at lower than design power levels. The best example of that is the incandescent lamp in which the filament is usually designed to operate as close to the melting point of tungsten as possible for high efficacy, but cool enough so that the lamp will still last a reasonable length of time.

Light output, efficacy, and life of general service incandescent lamps follow well known exponential curves /3/ as input power is varied with the result that a small reduction in power translates into a large reduction in light output. For example, operating a lamp at 80% of its rated wattage will cause it to provide only 63% of its rated light. Some incandescent lamp controls use diodes which supply half wave direct current to the lamp. In that situation the lamp operates at about half power, but emits only 25-30% of its rated light. A 100 watt general service lamp on a diode would therefore produce about the rated output of a 40 watt lamp, but it would be drawing nearly 60 watts to do so. Other changes in lamp operating characteristics as incandescent lamps are operated at lower power levels include an increase in expected life, lower bulb

surface temperatures, and a shift in color--relatively less blue, more red and yellow--indicative of lower chromaticity (Kelvin) values.

In discharge lighting systems proportional control can affect both the starting and operating processes. Starting involves the breakdown or ionization of gases in the lamp arc tube, the establishment of a hot spot on the cathodes, and the stabilization of the arc so that full output can occur. The sequence and timing of these events is important for proper lamp life and maintenance of light output over time. Traditionally, when operation of fluorescent systems at various output levels has been desired, special dimming ballasts and rapid start lamps have been employed. These dimming ballasts contain two separate circuits. The first energizes the lamp cathodes to ensure rated lamp life and stable operation over a range of output levels; the second controls the power in the lamp arc which determines the lamp's light output. These dimming systems require extra wiring, special lamp holders containing a disconnect switch, and the ballasts are relatively more expensive than standard ballasts because of the extra circuitry and limited demand. During the past few years as electronic dimming circuitry has been developed, fluorescent dimming systems have become somewhat simpler to install and they operate well, but dimming is still significantly more costly than switching.

Proportional energy controls designed for fluorescent systems do not generally employ special dimming ballasts. They utilize variable voltage, variable phase, or special proprietary circuits within the control device to control the input to the ballasts normally installed in the system. Their advantage is that they can be used in either new or existing systems without special wiring and, in some cases, without modifying the luminaire at all. To achieve this flexibility some controls may be limited to operating fluorescent systems in the upper part of their ranges. 75 to 100% is typical. Others, using special circuits, can go well below 50% of rated output, but none, as yet, seem to be able to duplicate the performance of dimming systems and take lamps into the 10% or lower range without encountering problems with lamp performance.

Another consideration which applies to fluorescent systems is the change in thermal characteristics as the lamp power level is varied. All fluorescent lamps are temperature sensitive as indicated in Figure 1. Lamps are rated at an ambient air temperature of 25 C (77 F) which corresponds to a lamp bulb wall temperature of about 38 C (100 F). Both lamp lumen and lamp wattage ratings apply at this point. As bulbwall temperatures increase, both lamp light output and watts go down just about in step so lamp efficacy remains fairly constant. Commercial indoor

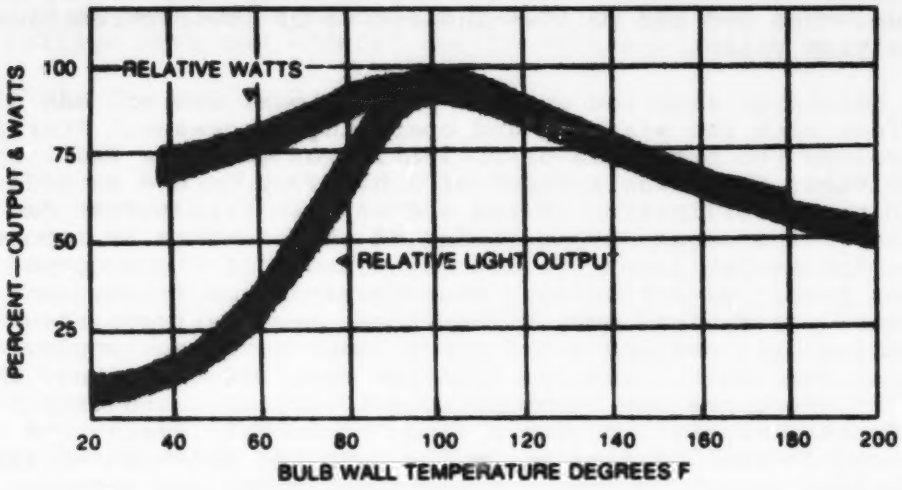


Fig. 1. Fluorescent Lamp Temperature Characteristics (General Lighting Lamps)

fluorescent luminaires normally operate fluorescent lamps somewhere in this range. Enclosed luminaires containing several lamps would operate the lamps well down on the right side of the curve. Open luminaires with one or two lamps or luminaires which exhaust room air over the lamp surfaces would operate near the peak of the curve.

If a control is added to the system and operates the lamps below rated watts, then the lamp operating temperature may shift to the left of the rating point peak. In this region the system efficacy drops because as the light output goes down, the watts remain relatively high. Figure 2 gives a more descriptive view of the situation and indicates that for a 4-lamp open luminaire, the system (lamp and ballast) would lose about 25% of its efficacy if operated at 50% of its rated output. This is not as severe a loss as with incandescent systems, but it is substantial. Implicit in Figures 1 and 2 is the caution that before meaningful measurements can be made the system must be thermally stable. Adjusting a fluorescent lighting control and immediately taking a reading of watts and light output will not yield correct data.

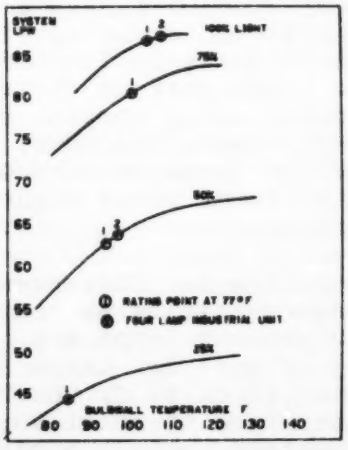


Fig. 2. System Efficacy Vs. Lamp Temperature At Various Light Outputs

Unlike incandescent lamps, fluorescent lamps do not change color significantly as light output levels vary. Normally, over the range from 25% to 100% of rated output, any changes would be virtually unnoticeable as indicated in Figure 3.

CHROMATICITY VS LIGHT OUTPUT*

LIGHT OUTPUT	T12 X	T12 Y	T8 X	T8 Y
100%	.3818	.3998	.3802	.3875
50	.3805	.3923	.3776	.3864
25	.7813	.3826	.3795	.3835
Y	.3812	.3949	.3796	.3969
Y	.0007	.003	.001	.005

* DATA TAKEN AT 77° F IN INTEGRATING SPHERE USING F40/CW LAMP WITH LITE WHITE PHOSPHOR OPERATING AT 25 KILOHERTZ

Fig. 3. Chromaticity Vs. Light Output

During starting, proportional fluorescent lighting control systems are usually bypassed so full power can be applied to the ballast and lamps. This is essential for slimline (instant start) circuits because rated lamp life depends upon the arc being established quickly. Rapid start circuits operate so[illegible] what differently. With these [illegible] has been found that a start-[illegible] scenario as indicated in [illegible]igure 4 has some energy saving advantages. Most currently available ballasts turn on the cathode and arc voltages as the ballast is energized, but a couple of electromagnetic and several electronic ballasts operate as follows: When the circuit is first turned on, cathode voltage is applied, but lamp voltage is held below the value necessary to establish the arc. After about 0.5 seconds the arc voltage is turned on and the arc started. Now the cathode voltage may remain on or it may be turned off after another 0.5 second stabilization period. It has been customary to leave the cathodes energized, but recent studies have indicated that about 5 watts per ballast (2-lamp electromagnetic type) can be saved if the cathodes are turned off. Switching may be done in the ballast with a special circuit /4/ or it may be done using a thermal switch inside the lamp on the lamp cathodes themselves. Published data indicate that the trade off for this power saving feature is about 5,000 hours

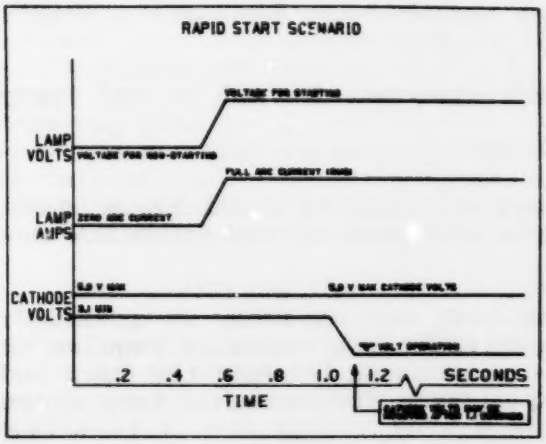


Fig. 4. Rapid Start Starting Scenario Being Implemented In New Ballast Designs

of rated lamp life, but this penalty may disappear as burning hours are accumulated during testing and future cathode improvements are made.

Much of the information presented above also applies to HID lamp systems. Starting the lamp at full power is important to minimize cathode sputtering, but lamps may be left to warm up either at full power or some controlled value. Lamp efficacy losses are always relatively greater for HID lamps than for fluorescent lamps when lamps are operated at less than full output. This is because HID lamp efficacy depends upon comparatively higher arc tube pressures and temperatures which change rapidly at less than full power. Color shifts are also more dramatic, especially with metal halide lamps, again because of temperature since lamp color depends upon the amount of halides vaporized and present in the arc at any given time. HID ballasts are available in a variety of circuit types and some of these have energy storage characteristics which would limit their use with some types of proportional controls.

While this material has emphasized some of the problems that might be encountered as proportional controls are applied to practical lighting systems, it should be stated that control systems have been designed and are available which anticipate and take many of these lamp and ballast characteristics into account. It is still up to the specifier, however, to be aware that not all controls can be successfully applied to all systems and careful evaluations have to be made. To assist in that task some experience-based guidelines have been assembled. These are summarized as follows:

APPLICATION GUIDELINES: MATCHING THE CONTROL TO THE SYSTEM

1. Start fluorescent and HID systems at full power.

2. Limit proportional controls used with discharge systems to the upper 50% of the system's output range for maximum system efficacy.

3. Check luminaires to be sure the assembly is grounded. Fluorescent system specifications normally require that a certain distance be maintained between the lamp and a grounded conducting surface for reliable lamp starting.

4. Lighting controls do not increase lamp or system efficacy (lumens/watt). As power is reduced, light will also be reduced. The ratio (power:light) can be close to 1:1 for some controls over a limited range.

5. Lamp and ballast warranties may not be honored by man-

ufacturers whose products will be operated outside of their normal specified ranges because of controls. Determine who is responsible for product performance and warranty service.

6. Realistically evaluate the savings available with controls. Are test reports or reliable performance information available? Did an independant laboratory or consultant do the study? Will a lighting energy reduction which also reduces the heat generated inside a building increase or decrease the net heating and cooling energy use?

7. Search for control "bonuses"--features that are inherent or come along automatically once controls are in place. Example: proportional fluorescent lighting controls may be able to do double duty as architectural lighting dimmers.

8. Consider the users of the space where controls are used. Will the space be more flexible or convenient? Is lighting quantity or quality going to be changed?

FACTOR II: THE POTENTIAL TO IMPROVE LIGHTING QUALITY

Lighting energy can be reduced in a number of ways such as removing lamps, disconnecting fixtures, installing control equipment or implementing various control strategies. Experience accumulated over the last few years has shown that it is relatively easy to reduce energy use in lighting systems and use the cost savings to justify and "pay back" whatever investment is involved. The idea is easy to understand and appealing to those who want to "get it done fast". Indeed, surveys* continue to show that simple pay back is the most often used rationale for energy saving investments. Manufacturers of control equipment know this and advertisments for lighting controls invariably feature pay back data -- often at the expense of important application and performance information.

But modifying the lighting system to use less energy means that its light output, appearance, operation, and other characteristics will also be changed. So, questions must be asked about the quality and quantity of illumination provided recognizing that before and after economic comparisons do not fairly rate a lighting control's effectiveness unless light itself is brought into the picture.

The lighting user and his or her lighting needs must come first. Lighting is, after all, designed for people.

---

*The results of two such surveys are reported in Energy User News No. 5, 1980 p.9 and No. 6, 1981 p.1.

In commercial settings it is put into place so that people can do visual work, so the merchandise can be evaluated and sold, and so that comfort and safety are maintained. But the amount of light flux is not the only parameter involved. It is known that illumination on a visual task leads to visibility and there is general agreement /5/ that seeing leads to human performance, even though there may be controversy about the factors involved and their relative importance.

The way the light is handled qualitatively in a space is, however, of equal importance. Lighting quality is made up of those factors which make lighting comfortable, stimulating, appealing, and attractive as well as productive.

It is, at this point, still difficult when applying controls to lighting systems, to determine how these various quality factors are changed. Glare is known to cause discomfort or, in extreme cases, visual disability. The color of light can strongly influence the feelings of people. The luminance distribution within a space helps determine how pleasant the space appears. But the scales of measurement are not exact. Illumination levels can be easily measured; quality, for the most part, cannot. This is being recognized and efforts are underway to put lighting quality on a more quantitative basis. /6/

Some designers working with lighting controls have already hinted that controls may offer opportunities to improve lighting quality. So, to assist the development of that idea, some suggestions have been listed in Table 1 and an experimental proposal follows.

METHOD: AN EXPERIMENT

Suppose that an office space is lighted uniformly with an array of lens bottom fluorescent luminaires distributed uniformly over the ceiling surface in a grid pattern. The task areas, however, are non-uniformly distributed with desks, tables, and other work surfaces placed at various angles with respect to the lighting equipment. The arrangement has been established by the needs of management, the people working in the space and the work flow. It functions well, but it is expected that as different work processes are implemented or departments change, some movement and rearrangement of the furnishings will be necessary. Those familiar with office operations will recognize that this is not an unusual situation.

Suppose further that the general lighting is provided by luminaires which can be individually controlled by dimmer switches. Each fixture, in other words, is equipped with a knob that can vary the output of the fixture from

OPPORTUNITIES FOR LIGHTING QUALITY IMPROVEMENT VIA LIGHTING CONTROLS

Control Function	Lighting Quality Considerations	Energy Considerations
1. Switch or dim individual lamps or luminaires. (Control the direction and intensity of light coming to the work surface.)	Glare, veiling reflections (reflected glare), texture, modeling.	Lighting supplied only where needed in the proper amount.
2. Balance daylighting and electric lighting.	Appearance of the indoor space. Minimize extreme luminance ratios. Psychological connection with outdoors.	Minimize use of electric lighting energy when and where daylight is available.
3. Compensate for lighting system deterioration.	Maintain appearance and design values.	Eliminate overdesign.
4. Provide controlled variation in color and brightness patterns.	Enhance visual interest.	Variation permits timed reductions in electric load.
5. Preset lighting patterns for planned uses of the space.	A designed rather than a random appearance of the space.	Allows correct mix of light sources and systems for optimum efficacy.

Table 1.

0 to 100 per cent. How should the luminaires be set so that each person in the space has ample high quality illumination over his or her work area?

One approach might be to instruct each worker to set the output of the luminaires to suit his or her individual needs. That could work well if the worker density is not high, but as more people become involved and begin to share the light from each luminaire, the geometry of the situation and individual differences would make it harder and harder to please everyone.

A second and slightly more elaborate approach might involve a lighting "expert". That person might suggest a few simple rules to guide the setting of the controls. The classic "have most of your work light come from over your left (or right) shoulder" is still good advice. To that could be added "reduce the output of the luminaire directly overhead and in front of your desk" and "lay a pocket mirror on your work surface and dim down the luminaires which are reflected in it as you hold the mirror at the angles you normally would use as you do your reading, writing, or typing tasks". These guidelines, as lighting designers have found, help to improve task visibility, minimize shadows, reduce veiling reflections or reflected glare in the task and control discomfort glare. In fact, in this hypothetical situation where the luminaire luminance can be fine tuned to just the right level for the individuals involved, the person could be expected to choose their own "borderline between comfort and discomfort" which is the basis for the Illuminating Engineering Society's Visual Comfort Probability system. /7/

Having a lighting "expert" involved might also improve the lighting results from a human relations standpoint. That person could mediate differences such as those arising where glaring luminaires for one person provide another's main source of light.

A third or analytical approach is also possible. Computer programs are available which can predict visual comfort probability and which can determine contrast, illuminance, luminance, and information about veiling reflections. Setting ranges of acceptable values for each work station, then using the computer programs in a deterministic mode, would result in the specification of optimum output values for each luminaire.

What might be the results of such efforts? It seems clear that lighting power would be reduced assuming, of course, that ample light had been provided in the original design. More difficult would be the problem of determining what adjustments had been made for factors such as glare versus adjustments for illumination level or psycho-

logical reasons. This is not a well researched area.

It also seems clear that some improvement in lighting quality would result as some luminaires were dimmed. Glare and veiling reflections can be comparatively judged so some balance should be reached that would appear to be better.

Would the lighting be anywhere near an optimum configuration and would the exercise be worth the time and effort? That is not clear, but it is timely and an idea which fits with the need to know more about the role of lighting quality factors and how they might relate to the problem of lighting energy conservation. A quantitative study could well yield some fascinating data.

SUMMARY

The objective in the application and integration of lighting controls is to be able to put each light source under control so its output can be varied, either individually or as part of a defined lighting system, smoothly and efficiently from off to full output. That time has not yet arrived. Indications are that the technology is within reach, but that more system thinking must yet be done to better electrically integrate controls with the lighting system and their application into the design process. It is becoming clear that there are some opportunities along the way with respect to the role controls might play in improving the lighting quality of lighting installations. So far, while the use of controls continues to grow rapidly and a multitude of hardware and ideas continues to appear, the emphasis has been on energy savings. It is now time to extend and complete the integration process.

REFERENCES

1. "Fluorescents -- On/Off", Lighting Design and Application. Vol. 3, No.1, January, 1973. p.39.

2. Dawson, C.W. et al. "Hot Spots and Their Effect on the Lives of Incandescent Lamps", Journal of the IES. Vol. 2, No. 4, July, 1973. p.381.

3. Kaufman, J.E. (Editor). IES Handbook. 1981 Edition, Reference Volume, Chapter 8, p. 8-9.

4. Hammer, E.E. and McGowan, T.K. "A New Optimised Fluorescent Lamp and Ballast For Low Energy General Lighting Applications", Conference Record. Industry Applications Society, 82CH1817-6, 1982. p.1335.

5. Op cit. Chapter 3.

6. National Electrical Manufacturers Association (NEMA) "Comments of the Lighting Equipment Division and Analysis of the Recommendations for Energy Conservation Standards and Guidelines for New Commercial Buildings". Report submitted to the U.S. Dept. of Energy, Washington, D.C. April 25, 1984.

7. Committee on Recommendations for Quality and Quantity of Illumination, "Outline of a Standard Procedure for Computing Visual Comfort Ratings for Interior Lighting", Illuminating Engineering, Vol. 61, No. 10, October, 1966. p.643.

LIGHTING CONTROL:
Some Conclusions

M.S. Rea
Symposium Chairman

ABSTRACT

The purpose of this paper is to tie together some of the issues associated with lighting control. It summarizes the information presented by the symposium participants and reflects many of the thoughts expressed on the subject by the researchers in our laboratory. To a large extent, it represents our interpretation of the subject and of the symposium.

CONTRÔLE DE L'ÉCLAIRAGE:
Conclusions

M.S. Rea
Président du symposium

RÉSUMÉ

Cette communication a pour but de relier entre eux certains des problèmes associés au contrôle de l'éclairage. Elle constitue la synthèse de l'information présentée par les participants lors du symposium et reflète les nombreuses idées exprimées par les chercheurs de la DRB. Elle représente dans une large mesure, le point de vue de la DRB sur le sujet et constitue le bilan de ce symposium.

Dr. M.S. Rea
Research Officer
Energy & Services Section
Division of Building Research
National Research Council of Canada
Ottawa, Ontario
K1A 0R6

ABOUT THE AUTHOR

Dr. Rea did his post-graduate work at the Institute for Research in Vision at Ohio State University, and received his Ph.D. in sensory biophysics in August 1978. Since that time he has been employed at the National Research Council of Canada. He is an official Canadian delegate to the Commission Internationale de l'Éclairage, the chairman of the Illuminating Engineering Society, Committee for the Recommendation on the Quality and Quantity of Illumination (RQQ), and executive secretary to the National Research Council Office of Lighting Research.

M.S. Rea
Agent de recherche
Section énergie et équipements
Division des recherches en bâtiment
Conseil national de recherches du Canada
Ottawa, Ontario
K1A 0R6

L'AUTEUR

M.S. Rea a fait des études supérieures à l'Institute for Research in Vision de la Ohio State University où il a obtenu son doctorat en biophysique sensorielle en août 1978. Depuis, il est à l'emploi du Conseil national de recherches du Canada. M. Rea est délégué officiel canadien auprès de la Commission internationale de l'éclairage, et président du Committee for the Recommendation of the Quality and Quantity of Illumination (RQQ) de la Illuminating Engineering Society. Il est de plus secrétaire de direction du Bureau de la recherche sur l'éclairage du Conseil national de recherches.

INTRODUCTION

Stated generally, lighting control provides for the delivery of light to a specific location at a specific time. This definition encompasses both the spatial distribution of light (optics) and the temporal modulation of light (switching and dimming). This symposium was devoted to temporal modulation, recognizing that the term 'lighting control' can be used (appropriately) in a broader sense.

There are three fundamental features of lighting control for the modulation of lighting:

(1) Hardware, which may range from a simple wall switch to complex computer hardware and peripherals.
(2) A sensor that responds to a stimulus (e.g., a photocell responding to light). This stimulus-sensor action precedes the activation of the hardware.
(3) An explicit or implicit decision process that occurs between sensor detection of the stimulus and activation of the hardware. This decision process, a critical, but sometimes forgotten, aspect of the modulation of lighting, can be carried out by a person or the control equipment can be 'programmed' to do it.

Figure 1 shows the relationship between these three features of lighting control. At the input stage, a stimulus (or more than one) influences a sensor. A decision is then made about the sensor output and the necessary action. Finally the modulation equipment (hardware) is activated or deactivated. The process can be very simple: one stimulus (light), one sensor (photocell), one decision (criterion photocurrent), and one activation ('on' or 'off'). It can also be quite complex: a computer can be programmed to consider any number of sensor inputs before the lights are modulated.

The stimulus-sensors and activation hardware are usually durable and reliable. Very often, however, a lighting control system fails to meet the objectives of the lighting designer or the building owner or operator because the decision process does not consider all the important factors before the hardware is activated. Switching the lights 'off' when someone is working is an example of an inappropriate decision, not a failure of the timer or the switching hardware. Thus, the decisions about when or where the lights are to be modulated will usually determine the success or failure of the system.

To understand the significance of the decision process in lighting control systems, it is important to consider three issues: the objectives, the factors and the methods involved in lighting control. These issues formed the conceptual core of this symposium.

OBJECTIVES

A lighting system is composed of the lighting itself (e.g., fixtures, lamps, ballasts, lenses) and the controls

(e.g., sensors, software, dimmers, switches). The objectives for lighting the space, which are to meet the needs of the occupant (e.g., McGowan, Boyce), should be foremost in the design and installation of the lighting system. For example, high illumination levels may be required to perform a difficult visual task while low levels may be required to establish the proper mood for eating dinner. Absence of light can also be an objective, as in the case of sleeping. These various objectives could conceivably be met with a static lighting system (i.e., one without controls). One could build different spaces with different lighting for different activities. For example, a room with the lights 'on' all of the time could be created for reading and one with no lights could be constructed for sleeping. Usually, however, this is a waste of human resources, space and energy.

Lighting control offers the possibility of changing the state of lighting, and, therefore, the way a space can be used. A simple light switch, for example, enables a person to read in a bedroom as well as sleep there. The primary objective of the switch in this case is to allow for multiple activities in one room. Even where there may be no space limitations, switching (say, to see slides in a conference room) makes it possible to eliminate the time taken by the occupants to move from one area to another. The primary objective of the switch in this case is to use human resources more efficiently. Even a room with a single function, such as an office, may not be used all of the time, so the primary objective of lighting control in this case is to reduce the energy portion of the building's operating costs.

The objectives of lighting control are thus to change the state of a lighting system so that building space, human resources and electrical energy can be used more efficiently. Clearly, these objectives are not the same as those for lighting a space. The latter are associated with meeting the needs of the occupant, which, for a given task, can be met (impractically) with a static lighting system. A proper lighting system, however, will reflect <u>both</u> the objectives for lighting the space and those for lighting control; otherwise, the system is less likely to be satisfactory.

FACTORS

There is an almost unlimited number of factors important to the design and selection of a lighting control system (Carrière et al.). User satisfaction and productivity, utility costs, heating and cooling, available hardware, and legal requirements are but a few. These will interact to give a net financial gain or loss to the purchaser (Crisp), whether one can actually quantify their impact or not. There are calculation procedures that can provide <u>precise</u> estimates of the financial losses or gains resulting from various lighting control alternatives. It is questionable, however, whether these estimates are <u>accurate</u> or <u>complete</u> because some important factors may not have been included or the interactions between factors may not have been delineated. There is good reason to doubt these

estimates largely because of the complexity of the problem and because of the dearth of objective data on the subject (e.g., Levy, McGowan).

Rather than rely on complex and unsubstantiated benefit-cost estimates, practitioners seem to rely on very simple analyses or on their own experience. This approach will produce less innovative and probably less efficient lighting control schemes. The current trend for consulting firms to guarantee energy savings in a client's building and then share in the savings may substantially change the situation (Levy). As more of these firms emerge, more accurate procedures for estimating energy use will likely be developed (although these may not be available for public scrutiny and subject to validation). 'Savings' from the operation of lights may not, however, be savings in terms of the overall operation of the building. Saving lighting energy by frequent switching may decrease lamp life, and the costs associated with more frequent or uncoordinated relamping may exceed the energy cost savings (McGowan). Furthermore, saving lighting energy may result in higher heating costs, and, depending upon the relative efficiency of the lights and the heating plant, could conceivably result in reduced savings or even a loss. Therefore, it is important to accurately characterize the interactions between the many factors associated with the operation of a building to have a realistic picture of financial losses and gains.

More complex and more important than an understanding of the costs associated with the operation of lighting and other systems in a building, is an understanding of how the modulation of lighting affects the occupant (e.g., Boyce, McGowan). Controls should not compromise the primary objectives of lighting the space, which are to meet the needs of the occupant. No one can determine accurately how modulating lights during working periods affects occupant productivity. It would be hoped that this action has only a marginal effect on performance (Crisp). Nevertheless, even if these effects on the occupant are small, their associated costs can conceivably be greater than any energy savings that might be realized (e.g., Boyce, Crisp). Salaries represent such a large proportion (about 90%) of building operating costs, compared to the energy costs (about 1%), that reducing lighting energy by half may result in a net financial loss if the occupant's productivity declines even marginally.

This potential for disrupting the occupant has led some to shy away from lighting controls when the space is occupied and to concentrate on energy savings when the space is unoccupied. Since the effects on the occupant of switching and dimming are uncertain, it seems logical to take an aggressive approach to energy saving when the space is empty and a cautious approach when the space is occupied.

METHODS

There are many ways to control lighting that would improve the efficiency of a building without compromising the satisfaction and productivity of the occupant. Lighting professionals prefer a variety of approaches, but there seems to be a consensus that the objectives

for lighting a space (meeting the user's needs) are best achieved with a local, manual lighting control, but that a central, automatic system is necessary to improve the efficiency of the lighting system; practitioners rarely select either a strictly manual or a strictly automatic approach (Carrière et al.). Clearly then, there seems to be a belief that automatic systems can compromise the user's needs but that people are not reliable when it comes to saving energy. This 'mixed' approach, while quite sensible given the current state of knowledge, may not be the most appropriate in all cases. Recent studies indicate, for example, that completely manual approaches can effectively reduce energy consumption (e.g., Crisp, Boyce). Other evidence suggests that people are flexible enough to abide by scheduled automatic approaches, especially where occupancy is regimented (Crisp).

What is needed are studies that will provide a better understanding of how various approaches to lighting control affect occupant productivity and satisfaction (McGowan). There is a trend in this direction, but the bulk of the studies are oriented toward centralized, automatic approaches to lighting control, often at the encouragement of manufacturers. Studies of the psychological effects of manual switching or dimming are more rare, likely because they are difficult to conduct and because there are fewer advocates of this approach. Because of the potential profit, manufacturers of automatic lighting control hardware have a strong motivation to conduct research and then promote 'high tech' systems. In fact, the marketing seems to have been so well done by the manufacturers that lighting professionals usually think 'automatic control system' when the phrase 'lighting control' is used. Certainly, however, instructions to the occupant about the appropriate use of manual wall switches can also be considered a form of lighting control.

The automatic or 'high tech' approach to lighting control has been quite useful in making buildings more energy efficient; however, there is more involved than the mere installation of a lighting control system. Many manufacturers do not just sell products; they also provide service and consultation to the customer. Some manufacturers will design, install and maintain the entire lighting system. But whereas automatic features will undoubtedly reduce energy consumption in a building, they may not be the most cost efficient or most pleasing to the occupant in all cases.

There are two drawbacks that make alternative, 'low tech' lighting control strategies such as local manual switching unattractive to potential customers. First, considerable time would have to be invested by the customer to explore and understand these other strategies. Rarely does the customer perceive this as worthwhile. Second, there is no clear responsibility for service or consultation associated with these 'low tech' approaches. The customer wants to be able to call on <u>someone</u> if problems arise. To actually make buildings more efficient, then, it may be necessary to rely on manufacturers who are willing to supplement their products with intelligent consultation and sound service. Hence, we have the current preference for 'high tech' lighting control systems.

On the other hand, energy management firms sharing in the cost savings from energy or some operators of publicly owned buildings could reduce the dominance of 'high tech' systems. If convincing research is conducted and if these groups are willing to take responsibility for promotion, service and consultation, alternative, perhaps better, 'low tech' approaches to lighting control may become more prevalent. Until that commitment is made, however, lighting control will probably continue to be closely associated with the manufacturers of 'high tech' systems.

THE SIGNIFICANCE OF THE DECISION PROCESS

The main objective of lighting control is to improve efficiency of buildings. The methods chosen to do this should consider all costs, in particular those caused by disruptions to the occupant. When the occupant is not considered, potentially large financial penalties may be unwittingly incurred. For example, sudden or frequent changes in the light level, say, in response to daylight, are disruptive to the occupant (Boyce); while the financial magnitude of this disruption may be difficult to calculate, it is potentially large. This is not to say that taking advantage of daylight is inappropriate, but rather the decision process associated with the method of taking advantage of it is inappropriate in this case.

It is necessary, then, to better understand the consequences of the decisions executed by lighting controls on building occupants. Some key questions are: when is it disruptive to modulate the lights in response to daylight or in adjacent, unoccupied spaces. When is it disruptive to force occupants to use manual overrides of automatic scheduling or to ask them to remember to turn lights 'off' when they leave a space? These issues seem to have been treated in a rather cavalier manner by lighting experts and professionals in the past, yet they could be the most important determinants of a successful lighting system. Clearly, we need to understand these issues better because of their potential to increase building operating costs.

The current emphasis in building management is, of course, on reducing operating costs, and it is impossible to ask building operators and legislators to wait several years before taking action to improve efficiency. Nevertheless, there are <u>prudent</u> steps that can be taken to reduce the possibility of inadvertent cost penalties due to disruption of the occupant. First, it is important that the objectives be clearly stated and that the factors relevant to the installation and operation of the lighting control be delineated. If the objective is to reduce operating costs by saving energy, one should establish a complete picture of capital and operating costs.

Second, one should make sure that the decision process, explicit or implicit in the lighting control method, minimizes the possibility for occupant disruption. A reasonable first step is to use a method that turns lights 'off' when a space is unoccupied; this has the lowest potential for occupant disruption. If one wishes to go a step further and modulate the lights when the space is occupied, sudden or

frequent changes in light levels should be avoided. Similarly, one should ensure that the resulting illumination levels and patterns do not reduce occupant performance or satisfaction. Low illumination levels, glare and non-uniform luminous distributions can, for example, impair visual performance. Some guidance in these matters can be obtained through professional illuminating engineering societies.

SUMMARY

Lighting control allows for the delivery of light to different places at different times. A control system has three fundamental features: a sensor responding to a stimulus, a decision process and the activation of hardware. The decision process is critical, and to appreciate its significance it is necessary to delineate the objectives, factors and methods involved in controlling lighting.

The main objective of lighting control is to make a building operate more efficiently. This can be done by reducing energy costs, by using a given space for more than one activity and by better utilizing human resources.

The most important consideration in the selection of a lighting control system is the occupant because small reductions in productivity can easily offset large and seemingly attractive savings of energy.

The methods for controlling lighting are varied, but successful ones have two features in common: they always make the building operate more efficiently, and they do not compromise the satisfaction or performance of the occupant. Lighting professionals seem to recognize these features and currently prefer to employ local, manual switches together with 'fail safe' features like central, automatic timing. This 'mixed' approach may currently be the most practical, even if it may not be the ideal.

Better consideration of the decision processes will increase the operational efficiency of buildings without hindering occupant satisfaction and productivity.

This paper is a contribution from the Division of Building Research, National Research Council of Canada, and is published with the approval of the Director of the Division.

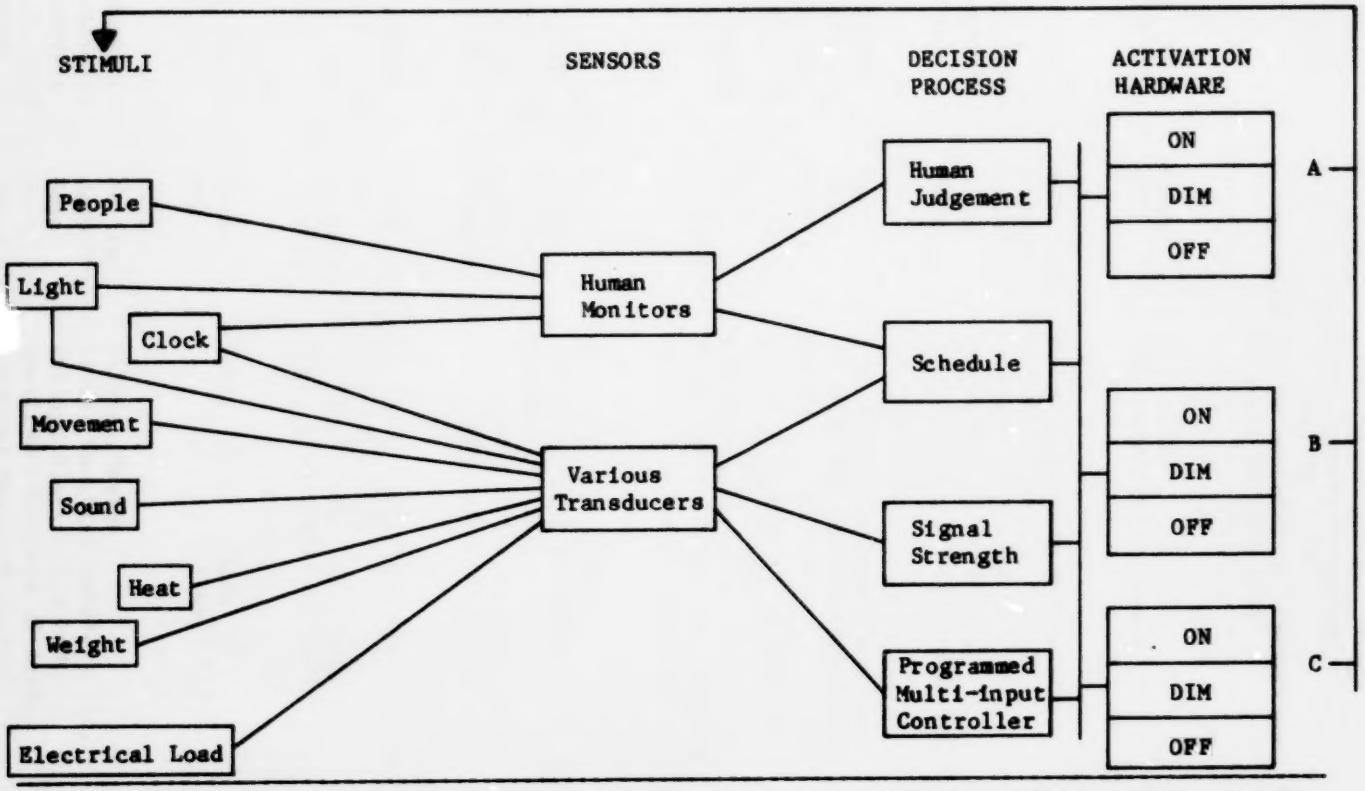


Figure1 - simple flow diagram illustrating the key aspects of modulating lighting with controls. Stimuli affect the various sensors in the lighting control system; these sensors in turn produce an input to the decision process. In the decision process, a comparator evaluates the input from the sensors; input that exceeds or falls below an established criterion leads to an output from this stage. Based on that output, the hardware controlling the lights is activated or deactivated. The new state of the lights can then be used as a feedback stimulus for subsequent modulations.

LIST OF ATTENDEES
LISTE DES PARTICIPANTS

Lighting Control Symposium
June 28, 1984
Symposium sur le contrôle de l'éclairage
Le jeudi 28 juin 1984

AHLSTROM	Robert	Prescolite	Ontario
ASHFIELD	Eric	PDM Electrical Products	Ontario
BAXTER	Rainford	McKee Lockhart & Assoc. Ltd.	Ontario
BIGGS	Ronald	National Research Council	Ontario
BOETTNER	Robert	US Dept. of Energy	Wash. D.C.
BOUFFARD	Robert	Les Ventes Electra Inc.	Quebec
BOYCE	Peter	Electricity Council Research Ctr	England
CANNING	Kerr	John Abbott College (Physics)	Quebec
CARRIÈRE	Louis	Canadian Electrical Association	Ontario
CHAGNON	Robert	University of Ottawa	Ontario
CHRYSLER	Allyson	Mulvey & Banani Int'l Inc.	Ontario
CHU	C.Y.	Public Works Canada	Ontario
CLARKSON	Brian	Philips Electronics Ltd.	Ontario
CORTH	Richard	North American/Philips Lighting	New Jersey
CRISP	Vic	Building Research Establishment	England
DALE-HARRIS	Hugh	Public Works Canada	Ontario
DEACEY	Peter	PDM Electrical Products	Quebec
DE GRANPRÉ	Gilles	Ventes P.T. Inc.	Quebec
DOUGLAS	Harvey	Canadian Electrical Association	Quebec
DRAKE	Pleasantine	Architectural Diagnostics	Ontario
EASTMAN	Jane	Canadian Electrical Association	Quebec
ELKINGTON	Ray	Wide-Lite Ltd.	Ontario
ELLISON	Margaret	Mt St. Vincent University	Nova Scotia
ENG	Stephen	Dept. of National Defence	Ontario
FINDLAY	David	Public Works Canada	Ontario
FONTYN	Mike	J.L. Richards & Assoc. Ltd.	Ontario
GABRIEL	Philip	Gabriel/Design	Ontario
GAUTHIER	Jean-Guy	Landry Gauthier Lefebvre Inc.	Quebec
GERVAIS	Roger	Philips Electronics Ltd.	Quebec
GILLETTE	Gary	American Institute of Arch.	Wash. D.C.
GOLD	Lorne	National Research Council	Ontario
GOODMANSON	Harold	Electrical Consultant	Manitoba

HANLEY	Peter	BFH/Shawinigan	Ontario
HUARD	Gilles	Hydro-Quebec	Quebec
JAEKEL	Ralston	National Research Council	Ontario
JARVIS	Ian	Energy Mines & Resources	Ontario
JEWELL	James	Pacific Gas & Electric Co.	California
JOHNSON	Kenneth	BFH Shawinigan	Ontario
KAUFMAN	John	Illuminating Engineering Society	New York
LABRECQUE	Camille	Expert Conseil en Éclairage	Quebec
LECLAIR	Jean-Guy	Le Groupe-Conseil S.M. Inc.	Quebec
LEGARÉ	Robert	Energy Mines & Resources	Ontario
LEVY	Alan	Rose Technology Group	Ontario
LEWIN	Ian	Lighting Sciences Inc.	Arizona
LOBDELL	Harry	Lithonia Lighting	Georgia
LOFTNESS	Vivian	Public Works Canada	Ontario
MCAULEY	Joe	Ottawa Hydro	Ontario
MCGOWAN	Terry	General Electric Company	Ohio
MCKAY	Hayden	Howard Brandston Lighting Design	New York
MACINTYRE	Norman	Public Works Canada	Ontario
MARCOTTE	Yvon	PDM Electrical Products Ltd.	Quebec
MARTINSON	Robert	Touch-Plate International Inc.	
California			
MEO	Rolando	Canadian General Electric	Quebec
MILLER	David	TransAlta Utilities Corporation	Alberta
MURRAY	John	PolyCom Systems Ltd.	Ontario
NIELSEN	Erling	City of Pointe Claire	Quebec
NE'EMAN	Eliyahu	Israel Institute of Technology	Israel
O'DONNELL	Brian	Engineering Interface Ltd.	Ontario
OUELLETTE	Mike	National Research Council	Ontario
PASINI	Ivaldo	Public Works Canada	Ontario
PEZOWLAS	Nick	Public Works Canada	Ontario
REA	Mark	National Research Council	Ontario
REID	Doug	Ontario Hydro	Ontario
ROBERTSON	William	Public Works Canada	Ontario
ROGERS	G.C.		Ontario
ROSENFELD	Anita	Public Works Canada	Ontario

SABOURIN	Jacques	W.S. Sales Associates Ltd.	Ontario
SOLTAU	Rupert	Giffels Associates Limited	Ontario
SQUILLACE	Stephen	Smith, Hinchman & Grylls Assoc.	Michigan
STENSON	Alexander	Public Works Canada	Ontario
STEPHENSON	Donald	National Research Council	Ontario
STEVENS	Shirley	Prescolite	Ontario
STYNE	Alexander	University of Miami	Florida
TIMMINGS	Martyn	Canadian General Electric Co.	Ontario
VERDERBER	Rudy	Lawrence Berkeley Lab./U. of Calif.	California
VILLENEUVE	Jack	Ontario Hydro	Ontario
VINCENT	Richard	Lighting Research Institute	New York
WEINER	Stefan	Delcan	Ontario
WHITE	Robert	Concordia University	Quebec
WOJDAN	Andrew	BFH Shawinigan	Ontario
WOOD	C.L.	Wood, Barani & Assoc. Ltd.	Ontario
WOTTON	Ernest	Lighting Consultant	Ontario
YOUNG	Paul	B.C. Hydro and Power Authority	B.C.
ZULAK	Joseph		